The TREND
IN ENGINEERING

at the University of Washington

In this issue:

A RESISTANCE-WIRE GRID SYSTEM

EFFECTS OF SYSTEM COMPONENTS IN PROCESS CONTROL

AN ANALYSIS OF TWO-DIMENSIONAL AND THREE-DIMENSIONAL GROUND-WATER FLOW BY ELECTRICAL ANALOGY

PORCELAIN ENAMELS FOR ALUMINUM

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WHAT IS HAPPENING TO THE LIBERAL ARTS?

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HAROLD W. STOKE

Dean of the Graduate School

HAROLD W. STOKE, who came to the University of Washington in the fall of 1951 as Dean of the Graduate School, received his A.B. degree from Marion College, Indiana, and his Ph.D. from Johns Hopkins University, in the field of political science. He has taught at the state universities of Nebraska, Wisconsin, Pennsylvania, and Tennesseee. In a distinguished career as an educational administrator, before coming to Washington, he had served as Dean of the Graduate School at the University of Nebraska and as Assistant and Acting Dean at the University of Wisconsin. In 1944 Dr. Stoke became President of the University of New Hampshire and in 1947, President of Louisiana State University, resigning early in 1951 to become Educational Advisor to the National Citizens Commission for Public Schools in New York.

IT IS GENERALLY ADMITTED that the traditional liberal arts no longer hold the dominant position they once held in higher education. In the opinion of some, this is good; to others, it is deplorable.

Among the numerous forces or trends which I believe have changed the position of the liberal arts in higher education are these four:

First, traditional liberal arts are felt to be altogether too narrow a framework on which to rest the educational structure needed today. They are considered inadequate (at least in the way they are presently taught) to serve as a basis for organizing and teaching the growing accumulations of knowledge.

This explains why the older subjects have given birth to new subjects which now lead independent lives. For example, botany and zoology are the parents of genetics, bacteriology, plant pathology, and the whole science of agriculture (to mention a few of perhaps 40 subdivisions of biology); psychology and education have long since overshadowed their parent, philosophy.

Second, the liberal arts have felt the impact of a vocational compulsion which affects more people more insistently than ever before. The masses who have recently found higher education necessary as well as available have been interested in making livings in the "agricultural and mechanical arts" and in the thousands of new ways in which our changing society wished to put them to work. Interest in learning, as represented by the traditional liberal arts, has been powerfully tempered by economic necessity.

The third basic force which has affected adversely the position of the liberal arts is a gradual shift in our educational values. This shift may be described as a decline of "learning," broadly conceived, as the highest value of education and its replacement by "competence."

Yesterday the educated man knew much of history—ancient, medieval and modern; he knew something of the lives of great men; he could identify the 13 decisive battles of the world; he studied foreign languages, and moral philosophy. He studded his conversation with literary allusions.

Today, "learning" may still be admired, but its acquisition is not considered vital. The educated man is the competent man. Competence does not mean narrow vocational training; rather it means the mastery of a substantial body of knowledge which can be put to immediate use.

The educated man of today does not aspire to breadth of knowledge; in fact he renounces it. He knows what competence in any field costs in terms of time and effort and he is likely to be suspicious of the man who pretends to more.

(Continued on page 29)

THE ENGINEERING EXPERIMENT STATION of the University of Washington was established in December, 1917, to coordinate investigations in progress and to facilitate the development of engineering and industrial research in the University. Its purpose is to aid in the industrial development of the state and nation by scientific research and by furnishing information for the solution of engineering problems.

The scope of the work is three-fold:

(1) to investigate and publish information concerning engineering problems of a more or less general nature that would be helpful in municipal, rural, and industrial affairs;

(2) to undertake extended research and to publish reports on engineering and scientific problems;

(3) to provide opportunities for graduate engineers to conduct research under conditions that will most effectively prepare them for professional service.

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2. Chemical Engineering, Industrial Chemistry
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6. Geology
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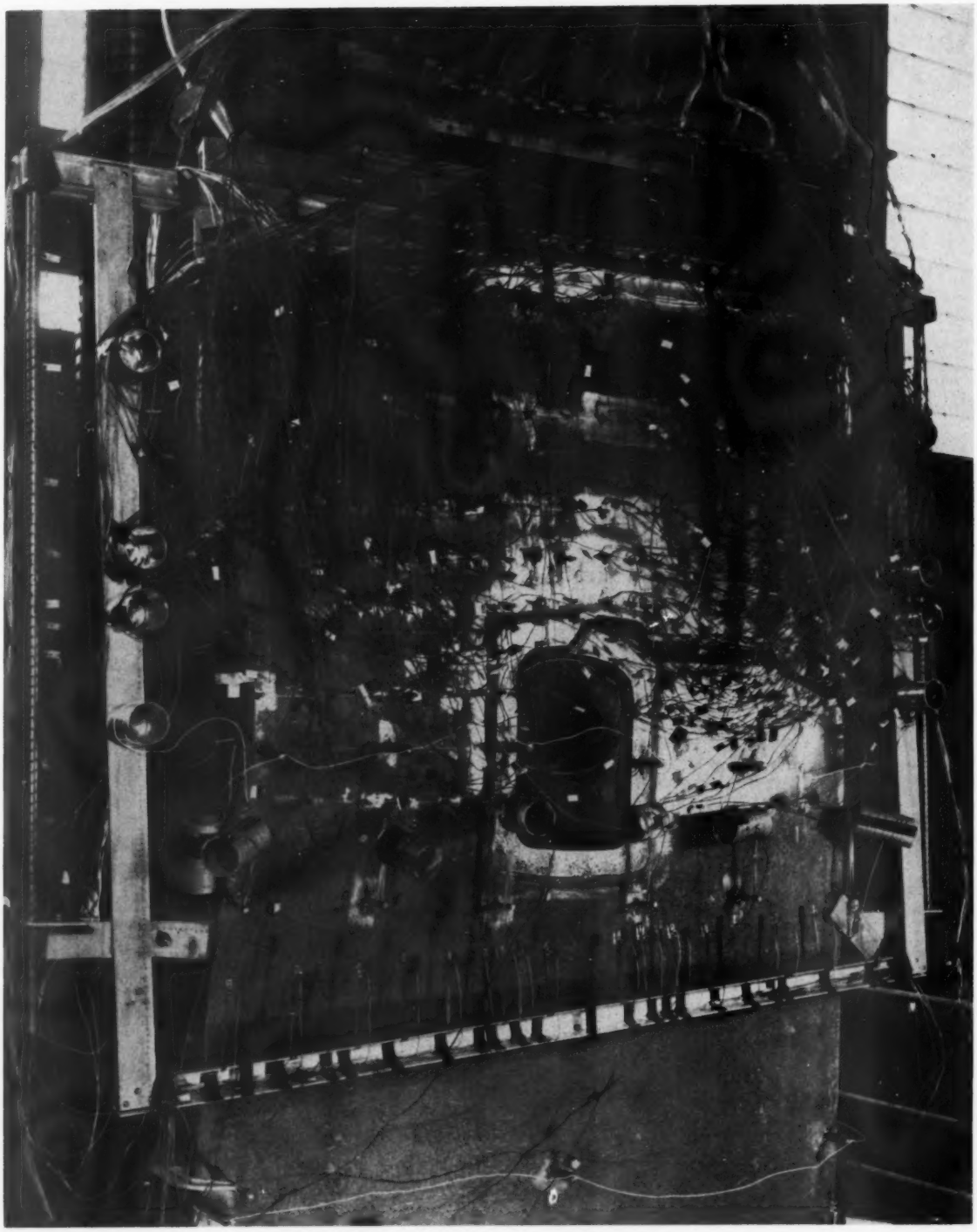

PLATE SPECIMEN WITH GRID SYSTEM AFTER TEST

Note that grid wires and most of the contacts are still in operating condition.

A RESISTANCE-WIRE GRID SYSTEM

DESI D. VASARHELYI

Assistant Professor of Civil Engineering

D. D. Vasarhelyi

Mapping the deformations of a plate which has some kind of a stress-raiser and which is stretched in its own plane, is one problem the stress analyst has to face, when studying phenomena in the plastic range. A solution is to lay out some grid system on the plate and to find some means of measuring its deformations while the plate is being stretched. This problem had to be solved in connection with the application of Nadai's octohedral shear stress method[1] in the analysis of the plastic deformation of ship plates with reinforced openings, part of a sponsored research project* the findings of which were reported elsewhere.[2,3,4] The project was carried on in the Structural Research Laboratory under the general supervision of Professor R. A. Hechtman.

A review of the applicability of the available methods resulted in the design of a new method: the use of resistance-wire gages in the form of a grid system. This proved to be a valuable method in solving the problem of mapping deformations without any interruption of the main testing process.

Introduction

Various techniques of making the grid and measuring it have been devised. The grid lines may be scribed with a sharp tool on the surface of the specimen, or indentations can be used to mark grid points. Or, the grid can be made by etching or transposing photographically the lines or marks on the surface of the specimen.

The change of distance of the scribe-lines, or of the indentations, can be measured by micrometers or microscopes, or it is possible to photograph the grid in different stages of the test and to carry out the measuring work on photographic plates.

All the above-mentioned methods present serious difficulties of application under the following conditions:

1. When the size of the specimen forbids easy handling, and thus its removal for carrying out measurements.
2. When the position of the specimen (e.g., enclosed in a cooling bag) does not allow handling of micrometers or photographing.
3. When a practically continuous test is required in order to avoid time effects interfering with the observations.

The last condition, the requirement of continuous readings, drew our attention to electric gaging methods.

It seemed possible to use feelers fixed to the grid points and sliding in contact with a surface made conductive by some kind of coating. Thus the change of distance of the points could be measured as a change of voltage between two points. The lack of a coating of sufficient uniformity at the time of the test eliminated this possibility.

The good results obtained at the same time with single slide-wire gages suggested the possibility of an application of slide wires. More thought on this subject and detailed investigation of the behavior of the slide wires resulted in the design of the system to be described here.

The Resistance-Wire Grid

The basic idea of the electric slide-wire gages is a very simple one. A wire of considerable resistance is fixed parallel to the gage line, one end solidly clamped to the end of the chosen gage length, the other attached to a fixture holding the wire in position. A slider is solidly fixed to the opposite end of the gage length and is in contact with the wire. When the gage length changes, the length of wire between the contacts changes simultaneously, and the voltage drop between the fixture and the sliding contact can be measured. This can be done by inserting the wire representing the gage in a Wheatstone-bridge circuit of any indicator built for a similar purpose.

It is possible to use one wire passing over a number of contacts or gage points, thus measuring the change of distance between a number of points. This can be done by alternately switching pairs of gage

* The work was sponsored by the Ship Structure Committee through the Bureau of Ships, Department of the Navy, Contract NObs-50238. The opinions expressed here are those of the author and do not necessarily represent the opinions of the Ship Structure Committee or any of its member agencies.

points to the indicator. The circuit type convenient for this arrangement is the four-arm bridge.

The second type of wiring suits the requirements of a slide-wire system for grid measurements.

In order to get the required resolution, the resistance of the section of the wire between the end points of the gage length should be as high as possible. This means that in the case of shorter gage lengths, those of smaller diameter should be used. The mechanical buildup of a slide-wire setup limited the minimum applicable strength of the wire to No. 36 (manganin), with a resistance of around 12 ohms per foot. This, on the other hand, determined the minimum gage length as one inch, on which a change of length of 0.001 in. could be accurately detected. Since the purpose of the measurements was the determination of deformations in the plastic range only, this was considered satisfactory.

The applicability of the slide wire to this type of work is influenced by various factors: the temperature, wire tension, and contact pressure.

All resistance wires change their resistance with the temperature. However, since the change of resistance as a function of the temperature is very small for manganin, manganin wire was chosen as having negligible temperature sensitivity in our test temperature range of +75° to −46° F.

Since the stretching of gage wires of small diameter changes their resistance, the effect of stretching on the resistance of the No. 36 wire contemplated for a grid system was investigated. Although the tensile stress in the wire varied from 9100 psi to 52,000 psi, no change of resistance was observed which could influence the expected accuracy of the grid-elongation readings. In other words, the No. 36 wire was still thick enough so that its change of resistance due to the tensile strain was far less than the change due to the 0.001-in. change in length. This means that it is not necessary to maintain a constant tension in the wire for the required 0.001 in. per inch accuracy, and any small change of the wire tension due to possible variations in the sliding contact would not influence the accuracy of the readings.

Another important part of a slide-wire setup is the contact point. It has to be built in the simplest possible way, else the work involved in the building of hundreds of such points can easily become prohibitive.

The simplest way to establish a contact point is to let the resistance wire slide across a copper lead wire. The resistance wire is slightly tensioned between the end fixtures. The contacting copper wire is in a slightly elevated position above the ends of the resistance wire. Thus the latter is somewhat bent at the contact point and presses upon the lead wire. As the contact slides along the resistance wire, the angle of the two parts of the wire changes and so does the contact pressure. This setup was investigated in order to find the possible influence of changing contact pressure. The No. 36 wire was tensioned by constant tensile force and a movable contact wire (No. 20 copper) was brought into contact with the resistance wire, to establish the electric contact. In consecutive steps, the contact point was raised by 0.01, 0.02, 0.03 and 0.05 in. above the level of the first contact. The setup was built for 1-in. initial gage length on the resistance wire, and readings were taken up to an elongation of 0.1 in. No significant variation of these readings was observed; thus variation in contact pressure conditions was assumed to have negligible effect.

Most of the generally available electronic strain indicators could be used for slide-wire work. These usually are built for SR-4 type gages, the average resistance of which is 120 ohms. In the case of slide wire, the total resistance of the slide wire being between 4 and 40 ohms, additional resistance in series should be applied to bring the total resistance within the range for which the indicator is built. Since the range of the above-mentioned instruments usually does not cover the wide range of the plastic deformations, a range extender should also be applied.

In our specific case, an indicator has been built with enough range to measure up to 30 per cent elongation of a maximum gage length of 6 inches in increments of 0.001 in.

Tests on a slide-wire setup built on a testing bench were carried out to check the linearity, the consistency, and the accuracy of the readings.

Complete linearity was observed by measuring elongation of one to two inches by 0.01-in. increments, or the elongation of one to 1.3 inches by 0.002-in. steps.

The general applicability of the slide-wire system from the point of the electrical setup is, however, only part of the problem.

The fact that a great number of sliding points should be attached securely to the specimen and should stay on during its severe stretching brought up the question of how to build and fix sliding contact points.

Since the type of the contact should be the simplest one, it was decided to use the bare ends of the lead wire as contacts. These had to be inserted in a plastic insulating holder, and the latter cemented to the steel plate specimen. Extensive investigation of some eight cements showed that a mastic type of cement will hold the insulators firmly on the plate while the plate undergoes an elongation of 20 per cent, and that it does not deteriorate in the test temperature range of +76° to −46° F.

Finally, tests of a smaller pilot grid system showed that a slide-wire grid can be built and successfully

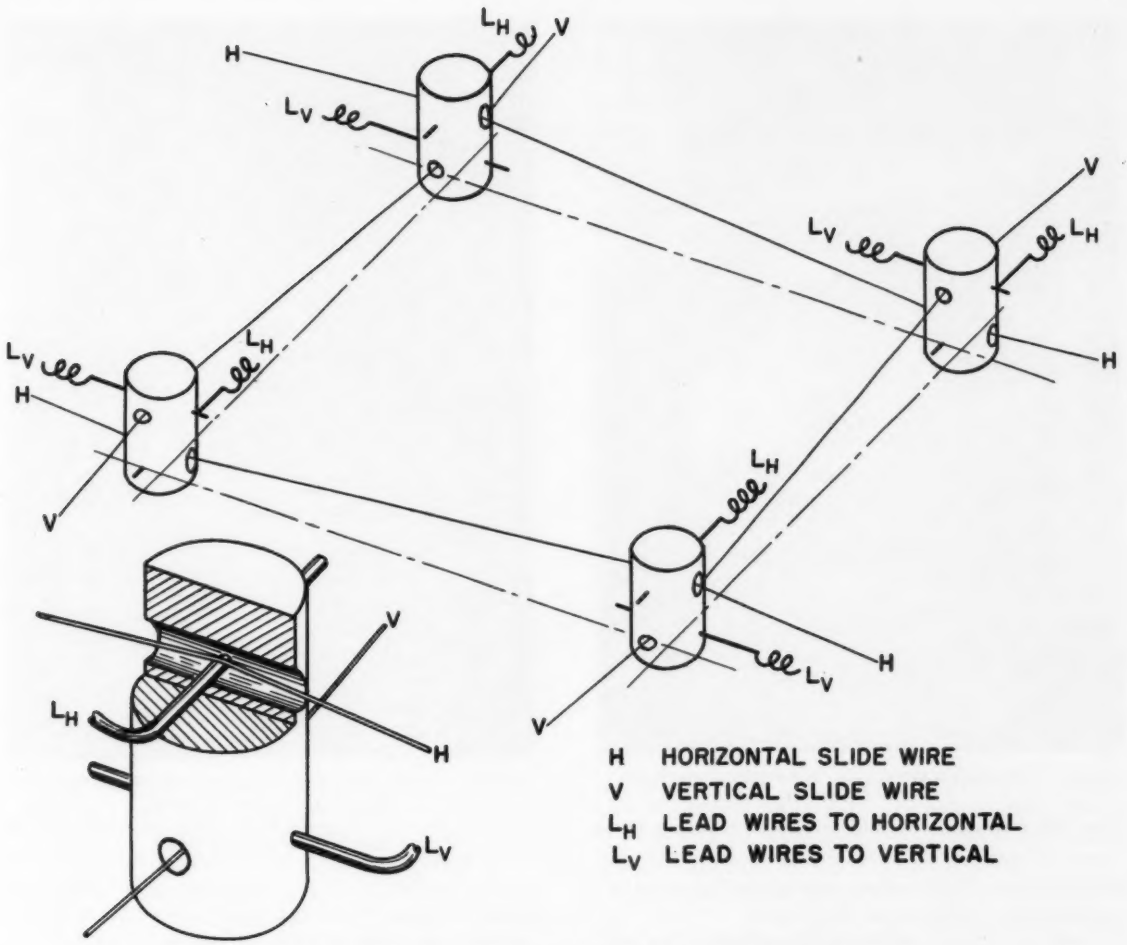

FIG. 1. SCHEMATIC ARRANGEMENT OF CONTACT POINTS AND GRID WIRES

operated. A schematic picture of one grid element is shown in Fig. 1.

The staggered arrangement of the contacts, as shown in Fig. 1, results in a slope of the slide wire. This slope is the steepest in the case of the shortest grid distance. The shortest distance between pegs is 1 in., in this case. If an elongation of 50 per cent is considered on a 1-in. gage length, with the given dimensions of the contact pegs, the change of slope would be 0.0334 (tangent). The cosine corresponding to this angle change is 0.99944, that is, it does not give a significant difference between the actual length along the wire and its projection on the gage line, and remains within the previously set limits of accuracy of 0.001 in. Morover, the slope in most cases is likely to be less steep than the one illustrated, since most grid lengths exceed one inch. Thus no correction due to the slope of the wires is necessary.

Application of the Resistance-Wire Grid on Wide Plate Specimens

The necessity of continuous measuring of elongations between a great number of points arose in connection with the study of the plastic deformations of plate specimens. The grid system had to cover areas of 36 by 18 in. and 48 by 24 in. A grid was designed with gage lengths ranging from 1 in. to 4 in. The number of points was around 130, and the elongation of about 220 grid lines had to be measured. The whole setup had to be built in such a way as to allow its insertion into a cooling bag and to secure good functioning throughout a test without any checkup.

Plastic pegs of ¼-in. diameter, were cemented with the proper adhesive to the intersections of the grid lines. The holes in the pegs were arranged in such a way as to secure the staggered positioning of the

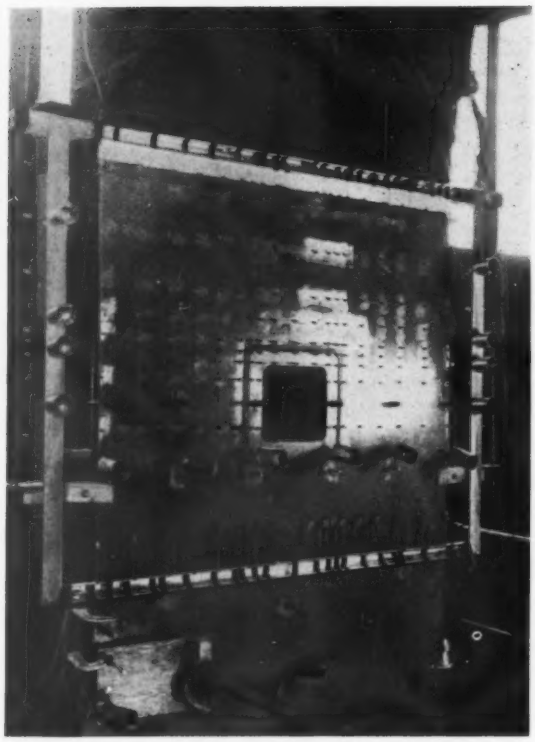

FIG. 2. PLATE SPECIMEN, CONTACT POINTS, AND GRID WIRES, MOUNTED

Note frame arrangement holding ends of resistance wires.

FIG. 3. PLATE SPECIMEN WITH LEAD WIRES TO EACH CONTACT POINT, MOUNTED

Note the set of plugs from which cable connection to the switch panel will be made.

contact wires. These contact wires were later slipped into the holes of the pegs (Fig. 1).

Both ends of each No. 36 manganin slide wire were clamped to small copper blocks on plastic holders. These holders were connected by elastic rubber bands to the frame holding the whole grid wire system. Two frames were provided, one for the vertical and one for the horizontal wires (Fig. 2). The top one of the two horizontal frame members, holding the vertical wires, was solidly clamped to the specimen plate, and moved with it during the test. The bottom one slid on the plate and was attached to two flats in solid connection with the top members. This made the whole system slide with the top of the frame during deformation and thus, the distance of the top and bottom of the frame being constant, the tension of the slide wires was also kept constant.

The end fixtures of the horizontal grid wires had to follow the extension of the plate. For this purpose two vertical bars, each at a distance of about 6 in. from the edge of the plate, were mounted in sliding holders. A helical spring was slid on each of the bars, and the ends of the spring were clamped firmly to attachments fixed to the specimen plate. Thus the spring elongated with the plate in the vertical direction and could not displace horizontally. The end clamps of the wires were attached to this spring. This arrangement was successful in maintaining simultaneously the horizontal position of the wires and their approximately constant tension throughout the test.

The sliding contacts were established by inserting the ends of the No. 20 copper lead wires into the plastic plugs cemented to the plate, and letting the manganin slide wire slide over it. The two contact wires required at each grid point then had to be carried to the switch board. The problem of a wiring system which would avoid confusion was successfully solved by using different colors for the leads of the horizontal and vertical systems. All lead wires were carefully numbered according to the wiring plan and joined to contact points of plugs shown at the top of Fig. 3. These plugs, in turn, were connected by cables formed of bundles of 20 wires to the switch panels (Fig. 4, left).

An important part of the setup is the switching system. Two switch panels, each containing ten

FIG. 4. INSTRUMENT STAND
Left: Switch panels. *Right:* Indicator unit

2-deck 20-point switches were built, one for the horizontal and one for the vertical grid wires. The manner in which the switch setup is built depends on the grid layout, the idea being to have one pair of points (the end points of any given grid distance) switched at a time to the terminals of the indicator. This takes care of what we may call the point switching.

The two ends of the particular slide wire on which the points are located should also be connected to the measuring unit. Usually two more switches are provided to switch the horizontal and the vertical wires, respectively, to the corresponding instrument terminals, while the point switch shifts the reading from one grid distance (one pair of points) to the others, in sequence.

The calibration of the grid system and the determination of the gage factor must be obtained as follows.

A grid wire, identical with those on the specimen may be set up on a calibrating bench. This should be at the same temperature as the grid, and all electric connections should be identical with those on the grid. There is a movable contact on the bench, the motions of which can be read by 0.001-in. increments on a dial gage. The readings through the electric system of the grid compared with known displacements of the sliding contact on the bench serve to determine the calibration factor.

It is also possible to build a slide-wire line exactly identical with those in the grid, but on a separate steel bar clamped at one end to the specimen. Thus the slide wire on this line undergoes the same temperature effects as those in the grid, the length of the gage lines remaining unchanged. The points of this calibration line, being at known distances from each other, give the readings for known lengths. The whole setup may be in the circuit during the whole test and the gage factor may be checked by this means at any time. This arrangement was used in connection with the low-temperature test. The check-line, as well as the whole specimen with the grid, was enclosed in the cooling bag.

The operation of the grid system during the test consists of two manipulations: switching and reading. It is best performed by two operators.

Recording of the readings should be carried out in tables especially set up for this purpose and giving a possibility of check at any point at any time. A good table is also convenient when it comes to the evaluation of the test data and the unit energy computations. A set of zero readings must be taken at zero load, since the great number of grid distances would require a prohibitive number of balancing potentiometers.

There is a possibility of checking the over-all elongations on the vertical and horizontal grid lines. The vertical values should compare with the readings of the long slide-wire gages spanned over the whole area. The last set (or any intermediate set) of the horizontal lines compare with the actual width of the plate at any load.

The functioning of the grid system was satisfactory, even in the first application. No contact points came loose during the test, and a few defects of the wiring were easily repaired without disturbing the readings. The large photograph on page 4 shows how well the grid stood up even while the specimen was broken; only a few of the contact points came loose and no grid wires broke. It would thus have been possible to operate the grid even after the specimen failed.

The grid gave very satisfactory results in the case of the low-temperature test, while all the intricate wiring was enclosed for about 15 hours in the cooling bag and there was no access to it during the test.

The change of the distance between the grid points could be measured at arbitrarily chosen loads without actual interruption of the test. It took about 40 minutes to complete one set of readings, and both load and temperature could easily be kept constant during this time.

Summary

1. It is possible to build a slide-wire grid system to cover a considerable test area of a specimen as large as those illustrated here, and to obtain continuous readings at any load position. The work involved in the building of such a system is not prohibitive.

(Continued on page 14)

EFFECTS OF SYSTEM COMPONENTS IN PROCESS CONTROL*

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P. L. Balise

During recent years automatic control has advanced rapidly, in being more widely applied and in the development of new equipment and mathematical techniques for analysis and design. This progress is certain to continue and to involve an increasing number of engineers.

In studying the subject, it is important to consider the entire process rather than to concentrate on the controller alone. A given precision of control can often be obtained more easily and cheaply by altering the process characteristics than by using a complex controller. Failure to realize this possibility has resulted in the wasting of considerable time and money.

The purpose of this paper is to show how the effects of process characteristics may be illustrated by analyzing curves obtainable from a demonstration process. Such a process is being built at the University of Washington, and, although the project is still in its initial stages, it seems worthwhile to present the information now available for its possible interest to others. This discussion will be confined to a mathematical analysis, typical reaction curves, and behavior under on-off control. Future work will include the application of other modes, but the on-off mode is sufficient to illustrate controllability.

The process, photographed in Fig. 1 (and schematically drawn in Fig. 3), consists of two tanks through which water continuously flows. The cross-sectional area of each tank can be changed, as can the resistance to flow between the tanks and at the outlet. The level of Tank No. 2 operates a valve in the inlet line, through a pneumatic controller. The photograph differs from the schematic drawing in the inclusion of additional devices being used in the present development of the equipment, such as a valve positioner, supply tank bypass, and controller bypass.

Liquid level was chosen for the controlled process variable because it is most visually impressive to the student and because it affords opportunity to illustrate principles in other engineering fields, such as fluid mechanics. A few similar devices have been built, notably one which is shown in the film on automatic control, issued by the Instrument Society of America.

The use of liquid level presents difficulties, particularly in selecting components that will give suitable reaction times, and in tuning the system to demonstrate the desired behavior. One of the unique features of this controller is that the effective tank areas can be changed without stopping the process. This is accomplished by having each "tank" consist of two tanks connected by a large gate valve. When the valve is open, variation of the levels is essentially identical, giving the effect of a single large tank.

It is appropriate first to analyze the process behavior as predicted by equations of the system. Consider first just a single tank (Fig. 2), with the following notation:

q_i = rate of inflow (gallons per minute, or similar units)
q_o = rate of outflow
C = tank capacitance (gallons per foot of height)
R_o = outlet resistance (feet of height per gallon per minute)†
y = height of water in tank
t = time

If a change is made in inflow, the level will change according to

$$C\frac{dy}{dt}=q_i-q_o\,, \tag{1}$$

that is, the capacitance times the rate of change of height equals the net flow into the tank.

The outflow is proportional to the head, or

$$q_o=\frac{y}{R_o}\,.\dagger \tag{2}$$

Equation 1 then becomes

$$R_oC\frac{dy}{dt}+y=R_oq_i. \tag{3}$$

An illustration of the behavior of this process may be obtained by considering a sudden change of

* The author wishes to acknowledge the assistance of Mr. Seth Thomas of the Johnson Service Company, donors of most of the equipment described here; and of Mr. Richard Leuba, who built the unit.

† This assumes that flow is proportional to head instead of to its square root, giving a linear equation which is easier to solve and visualize than the more exact one, and which gives the same kind of results as the exact system.

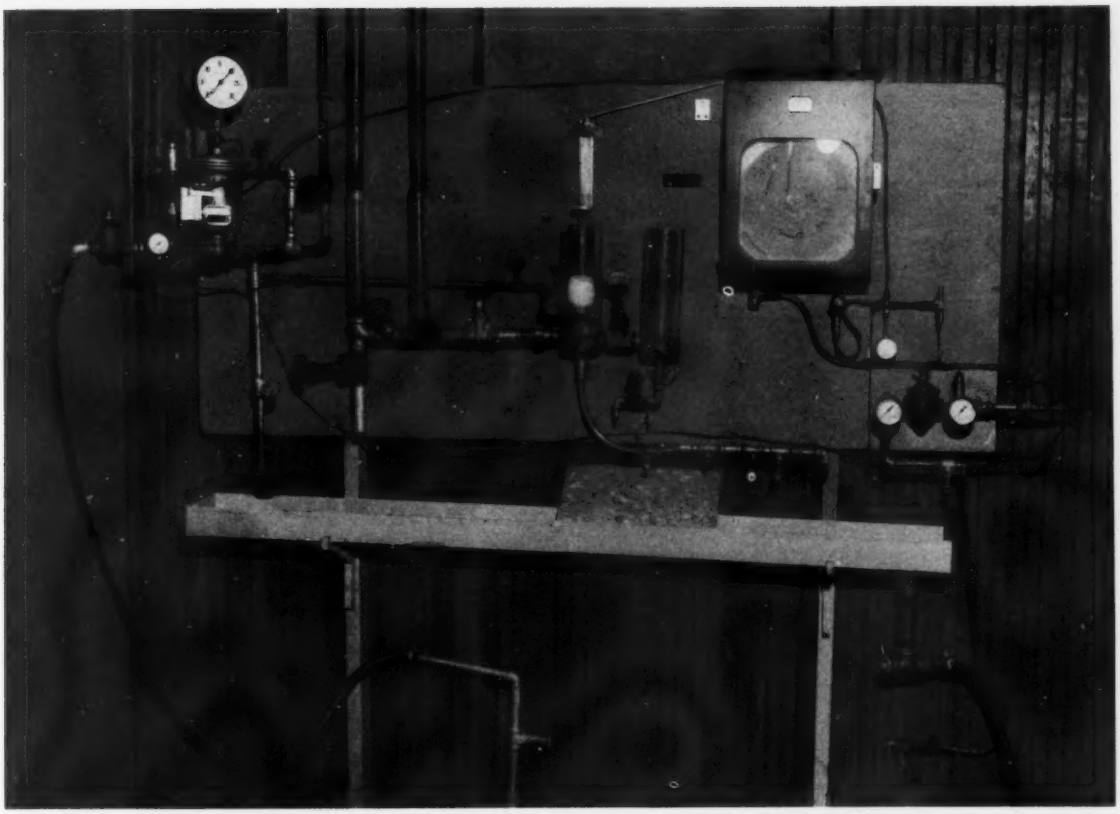

FIG. 1. LIQUID-LEVEL PROCESS FOR DEMONSTRATING AUTOMATIC CONTROL

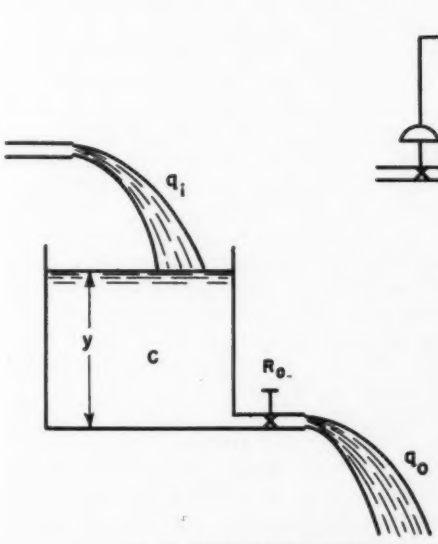

FIG. 2. FIRST ORDER PROCESS

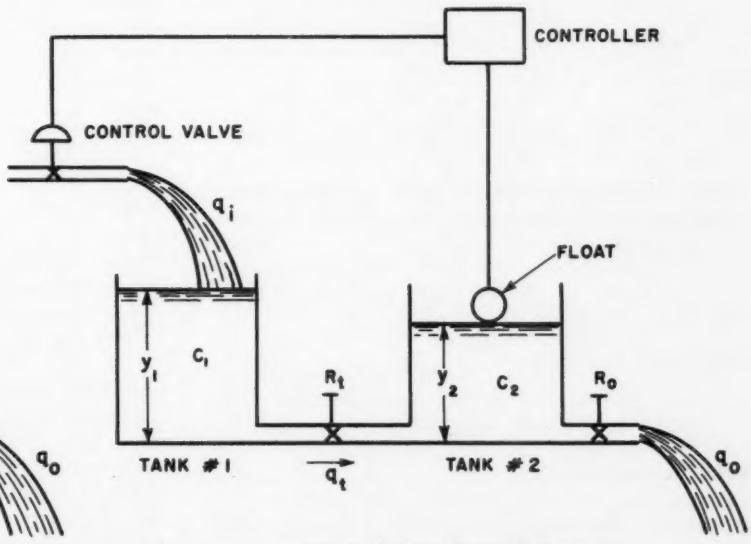

FIG. 3. SECOND ORDER PROCESS

inflow from zero to some constant value, Q_i. When equilibrium is finally reached, $q_o = Q_i$, and using this we may get an expression for the imput, Q_i, in terms of the final height, Y_F, from Eq 2 as follows:

$$Q_i = \frac{Y_F}{R_o}. \tag{4}$$

Using this expression for the input in Eq 3 yields

$$R_o C \frac{dy}{dt} + y = Y_F. \tag{5}$$

This is a first order linear differential equation which may be solved for y thus,

$$y = Y_F + (Y_I - Y_F)e^{-t/R_oC}, \tag{6}$$

where Y_I is the initial level in the tank.

As would be expected from looking at the system, the level immediately begins to rise, approaching its final value exponentially.

Now let us consider the addition of a second capacitance and a second resistance, as shown in Fig. 3. Changes in level in Tank No. 1 will be in accordance with

$$C_1 \frac{dy_1}{dt} = q_i - q_t, \tag{7}$$

and in Tank No. 2 with

$$C_2 \frac{dy_2}{dt} = q_t - q_o. \tag{8}$$

Also,

$$q_o = \frac{y_2}{R_o}, \tag{9}$$

and

$$q_t = \frac{1}{R_t}(y_1 - y_2). \tag{10}$$

The following procedure combines these four equations into a single equation:

From Eq 8 and 9,

$$q_t = C_2 \frac{dy_2}{dt} + \frac{y_2}{R_o}. \tag{11}$$

Substituting this in Eq 7,

$$C_1 \frac{dy_1}{dt} = q_i - C_2 \frac{dy_2}{dt} - \frac{y_2}{R_o}. \tag{12}$$

Differentiating Eq 11,

$$\frac{dq_t}{dt} = C_2 \frac{d^2y_2}{dt^2} + \frac{1}{R_o}\frac{dy_2}{dt}. \tag{13}$$

Differentiating Eq 10,

$$\frac{dq_t}{dt} = \frac{1}{R_t}\left(\frac{dy_1}{dt} - \frac{dy_2}{dt}\right). \tag{14}$$

Equating Eq 13 and 14,

$$\frac{dy_1}{dt} = R_t C_2 \frac{d^2y_2}{dt^2} + \frac{R_t}{R_o}\frac{dy_2}{dt} + \frac{dy_2}{dt}. \tag{15}$$

Substituting Eq 15 in Eq 12 gives

$$C_1 C_2 R_t R_o \frac{d^2y_2}{dt^2} + \left(C_1 R_t + C_1 R_o + C_2 R_o\right)\frac{dy_2}{dt} + y_2 = R_o q_i. \tag{16}$$

We thus have a single equation expressing the behavior of y_2 in terms of the input q_i and the constants (C_1, C_2, R_t, R_o) of the system. It should be mentioned that if the Laplace transform method is used, the transfer function of each component can be written, and the over-all transfer function is the product of those of the cascaded components. This process results in a transform which, by inspection, is that of a second order equation, and, moreover, each additional component will further raise the order of the equation. However, the classical method employed above is convincing for those students whose familiarity with transfer functions is limited, and it involves about the same labor, provided that more complicated systems are not considered.

Comparing Eq 16 with Eq 3 shows that the addition of a second resistance and capacitance has resulted in a similar differential equation for the height of liquid, but of second order. An equation of the same form as Eq 3 applies to the motion of a spring with damping; if mass is added, an equation of the form of Eq 16 results. It is significant that, in the liquid level system, the order of the equation is increased without the addition of a new kind of component but merely by the addition of a second pair of the same components present in the first order system.

The analogy between a process and a mechanical system, or an electric circuit containing inductance (mass), resistance (damping), and capacitance (spring), is thus developed. Similar applications may be made to systems involving temperature (with the system components measured by specific heat and thermal resistance) and many others. It also follows that various complex combinations of more of the same elements will obey more complicated differential equations of higher order.

In such cases, the differential equation is usually not solved directly for the response of the system, since this involves considerable labor and the effects of the individual system parameters are obscured in the complexity of the response. Recourse is made to such methods as transfer function plots from which

information on stability and other desired characteristics of the system can be obtained. There may also be difficulty in obtaining mathematical terms that are reasonably close approximations of the physical components. Analogs such as the liquid level process are, therefore, of limited use in correlating actual response with calculated response of complex systems. Instead, analog computers may be employed. However, the analysis of the two-capacity process serves to show how a higher order equation results from combinations of simple components.

A step input to the system of Fig. 3 may be analyzed in a manner similar to that for Fig. 2. From Eq 16 it is evident that the solution for the value of the height of liquid in Tank No. 2 is the sum of two exponentials if $(C_1R_t + C_2R_o + C_1R_o)^2$ is greater than $4C_1C_2R_tR_o$, and otherwise the solution is oscillatory. That the system cannot be oscillatory is evident because this inequality is equivalent to stating that $(A+B+C)^2$ must be greater than $4AB$ for positive values of A, B, and C, which by expanding is readily proved always to be true.

The rate of change of level in Tank No. 2 will then build up from zero to a maximum (assuming the process to be initially in equilibrium), and then approach zero as the final level is approached. This of course is also the characteristic behavior of an overdamped mechanical system. It is also interesting to note that if the value of any of the process components becomes zero, the response equation clearly becomes that of a first order system.

If the equation of the process is written with the inclusion of the automatic controller feedback loop, it becomes considerably more complex, especially for discontinuous functions such as are produced by the on-off controller. However, an indication of the controllability of a process can be obtained from its open loop (no controller) reaction to changes in the final control element (inflow valve in this case). The second order process, with its initial lag as predicted by the equations discussed above, would usually be more difficult to control than the first order process, which reacts immediately to adjustments of the valve.

Examination of the second order process shows that we may consider it as having a supply capacitance (Tank No. 1) and a demand capacitance (Tank No. 2), with transfer resistance between. A large supply capacitance is generally associated with greater control difficulty, in that a control valve change will be delayed in affecting the demand tank because it must first satisfy the supply tank capacitance. A large demand capacitance, on the other hand, tends to stabilize the process, since its level tends naturally to vary only slightly when there are process disturbances. Other lags, such as those in the controller, make the situation more complicated than

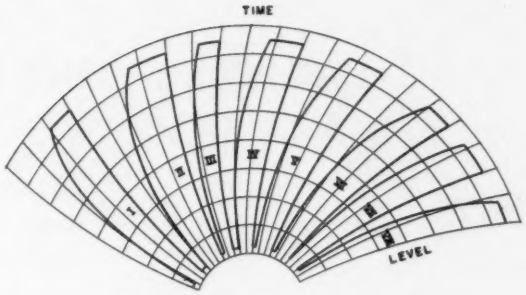

FIG. 4. PROCESS REACTION CURVES

this, so that the behavior of the process depends on the comparative values of all its parameters, rather than being predictable on the basis of the value of only one component.

It may be of interest to note two sets of curves taken from the liquid level demonstration process, even though its construction and adjustment have not yet been carried to the point where completely illustrative curves can be obtained.

Figure 4 is a set of reaction curves, the responses to sudden opening of the control valve, with the tanks initially empty. (The controller is cut out of the circuit.) Each curve shows an initial flat until the level rises sufficiently to actuate the float, followed by a gradual rise until the upper limit of float travel is reached.

The settings for each curve are as follows:

CURVE	SUPPLY TANK	TRANSFER RESISTANCE	DEMAND TANK
I	small	high	large
II	large	high	large
III	small	high	small
IV	large	high	small
V	small	low	large
VI	large	low	large
VII	small	low	small
VIII	large	low	small

One partial criterion for process difficulty is the product of initial lag and maximum reaction rate, a process showing long lag followed by rapid change being more difficult to control. The true initial lag cannot be obtained from Fig. 4 because of the limited float travel (a difficulty which will be overcome by utilizing tank pressure to measure level), but it may be approximated by noting the initial delay time.

The approximate product of delay time and maximum reaction rate increases in the order: I, II, III, IV. This is in accord with the previous discussion, small supply and large demand capacitances giving a small product, and vice versa. Also, in all cases with low transfer resistance, the product is smaller than with any of the high resistance cases, low transfer resistance being conducive to easy control. The

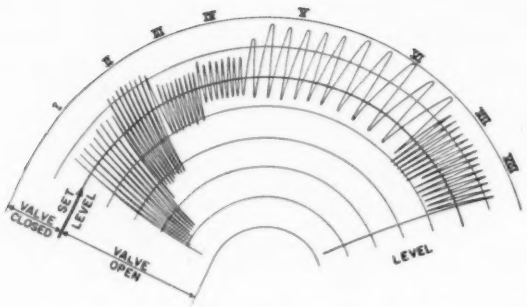

FIG. 5. PROCESS BEHAVIOR WITH ON-OFF CONTROL

system then actually becomes essentially the first order case with only one effective capacitance tank.

Figure 5 illustrates the process behavior with two-position control and with various parameter values. The settings are as follows:

CURVE	SUPPLY TANK	TRANSFER RESISTANCE	DEMAND TANK	OUTLET RESISTANCE
I	small	low	small	low
II	small	low	small	moderate
III	small	low	large	moderate
IV	small	low	large	high
V	small	high	large	high
VI	large	high	large	high
VII	small	low	small	high
VIII	large	low	small	high

The effects of the various changes are evident from the records. It is interesting to note the variation in average value and in frequency, as well as the changes in amplitude of cycling.

The amplitude is reduced (easier control) by reducing the load (increasing outlet resistance) in II compared to I; or it may be said that in II the system capacitance is larger relative to the load than in I, and therefore is more self-regulatory. The average level is also brought closer to the desired level, since with the reduced load the valve need not be open such a large percentage of the time.

In III the amplitude of cycling is again reduced, by increasing the tank capacitance. However, now the average value is not changed, since with the same load the valve must be open the same percentage of time.

In IV the load is further reduced, again reducing the amplitude and raising the average value as in II. The load is now so small that the valve is open less than half the time.

In V the transfer resistance is increased, effectively changing the process from a single capacity to a second order system. The slower response of level in the demand tank to changes in the valve is evident from the increased period and amplitude of cycling.

In VI the supply capacity is increased, making the process somewhat more difficult to control, as discussed earlier. The poorer controllability is indicated by the increased amplitude of the record.

Numbers VII and VIII afford an interesting comparison with V and VI. In both cases the supply capacity is increased, but in VII and VIII the transfer resistance was low so that the process had essentially a single capacity. Thus an increase in the "supply" capacity is in effect an increase in the single capacity of the system. Such an increase results in better controllability, as previously discussed, evidenced by the reduced cycling amplitude in VIII compared to VII. On the other hand, the same change in the two-capacity system results in increased amplitude, as shown by VI compared to V.

These illustrations indicate some of the ways in which the effects of process characteristics in automatic control may be demonstrated. It is hoped that they may provide stimulus toward a more vivid presentation of this rapidly developing subject.

A RESISTANCE-WIRE GRID SYSTEM

(Continued from page 9)

2. The operation of a slide-wire grid system presents no more difficulties than the operation of a great number of individual electric gages. Readings can be taken fast enough to assure a practically continuous testing.

3. The whole setup can be built with inexpensive, readily available commercial materials and fittings. With only minor adjustment, any electronic strain-gage system could be adapted to take readings off a grid system.

4. Once a sufficient number of contacts and wiring are manufactured and a switchboard is built, various types of grids could be covered. The whole equipment can be reused in a great number of tests.

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ANALYSIS OF TWO- AND THREE-DIMENSIONAL GROUND-WATER FLOW BY ELECTRICAL ANALOGY

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The various phases of Soil Mechanics, such as earth pressure, bearing capacity of soils, stability of slopes, and seepage, are far from being fully explored, and will continue to demand considerable attention. Their effects are almost always inter-related in any big problem as, for example, in the case of seepage. If seepage exists in a foundation problem, it may influence the bearing capacity of the soil, or the earth pressure against a retaining wall, or the stability of slopes.

In approaching the problem of seepage at least five methods have been developed:

1. Graphical solution by trial sketching
2. Theoretical or mathematical solution
3. Capillary flow analogy
4. Earth models
5. Electrical analogy

All of these methods have certain features in common. To solve the problem, we are interested in knowing the paths or the flowlines which a particle of water follows in its course of seepage through a saturated soil mass, and the water pressure at different points. The water pressure in a section is always given by the equipotential lines which, by definition, determine points where the total pressure head of the water is equal. A system of flowlines and equipotential lines is called a flownet.

In isotropic soil, flowlines must cross equipotential lines at right angles; in two-dimensional problems, a flownet made up of squares is preferable for the calculations.

When planning a model test we may choose a two-dimensional or three-dimensional model. Since the two-dimensional model is much easier to build than the three-dimensional model, it is always used where practical.

Some of the available methods can be used only in two-dimensional models. However, a main advantage in the use of the electrical analogy method is that it can be used to solve three-dimensional as well as two-dimensional problems.

The Electrical Analogy Method

The electrical analogy method is so-called because of the analogy between the mathematical equations which express the flow of percolating water and the flow of electricity. In other words, the ratio of seepage to head dissipated in unit distance is analogous to the ratio of current to voltage drop.

The electrical analogy method has, in many tests, proved its numerous advantages over other methods. In most cases it is more rapid and exact than graphically constructed flownets, and it is more economical in use than any other method. Of course this method has its limitations, but if they are recognized results of practical value will be obtained.

The greatest disadvantage of this method is that the top flowlines, the phreatic lines, must be located by trial.

Fundamental Assumptions of the Theory

In seepage analyses two assumptions are made:

1. Darcy's Law is valid.
2. The soil is homogeneous and isotropic.

A third assumption must be recognized before the electro-hydraulic analogy is valid, i.e., that this analogy is valid only for steady, irrotational fluid flow and steady electrical current flow.

Expressing these assumptions mathematically, we have an equation similar to an equation expressing the conditions for a steady current flow, thus exhibiting the analogy between the electric and hydraulic problems.

Having accepted the similarity between Ohm's law and Darcy's law, we can tabulate the comparable quantities involved in the following analogy, where n represents the general case of x, y, and z.

* Mr. Opsal has been in the United States under the sponsorship of the Institute of International Education (I.I.E.) and the American-Scandinavian Foundation.

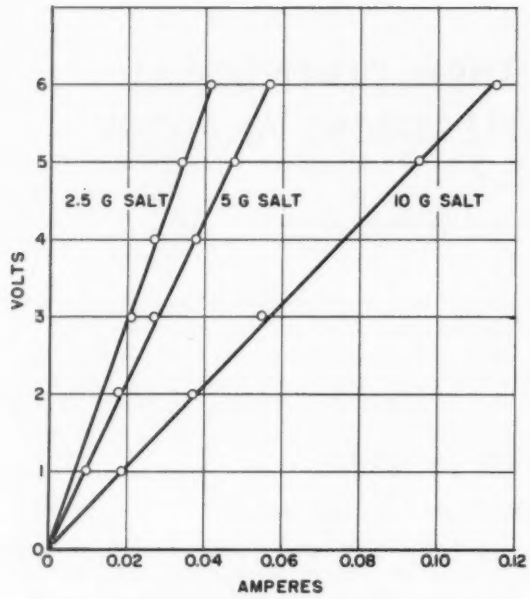

FIG. 1. ELECTRICAL RESISTANCE OF GELATIN AS A FUNCTION OF SALT CONTENT

Darcy's Law
(Prototype)

q_n = quantity of percolating water (cfs),
k = coefficient of permeability (cu ft/sq ft sec),
i_n = n-component of the hydraulic gradient.

Ohm's Law
(Model)

I_n = current flowing in model (amp),
k' = conductivity coefficient of model (mhos),
E_n = n-component of the electric potential gradient.

Model Requirements

In many fields, the use of model tests requires model formulas to transfer the results from the tests into practical use. In this case such a procedure is unnecessary.

In building a model in which the electrical characteristics are analogous to the percolation characteristics of the prototype, a conductive material through which electrical current can flow is substituted for the granular material through which water percolates, and a voltage drop is placed on the model where a head drop exists on the prototype.

The physical dimensions of the model and the prototype are kept in proportion.

The conductive material in the model is determined by the problem we are going to solve. Means used in a three-dimensional case may differ from those in a two-dimensional case. The requirement for the conductive material is that it be homogeneous so that the electrical resistance is constant. In some cases a liquid may be used; in others, a solid material. The most commonly used liquid is salt water. Its conductivity may be increased by adding salt. In two-dimensional problems with layers of different permeability, salt water can be used because the variations of the permeability can be expressed by variations in the depth of the liquid. In many three-dimensional problems this cannot easily be done. In cases with extreme differences of permeability, a good conductive material, such as copper, may be used for the extremely permeable layer.

Where the prototype is symmetrical about a plane or a line, a representative section may be formed of a solid material, such as pressed carbon. The desired results can then be obtained by tracing the flownet on one of the long sides of the model.

In all sedimentary deposits, as well as in most earth embankments, there is a tendency for the permeability to be greater in the horizontal than in the vertical direction. The horizontal coefficient of permeability may often be as much as ten times as large as the vertical value. Unless we can take this into account when constructing our model, the flownet will not be of great value for the solution of the problem. Going back to the fundamental equations of seepage, we can conclude that the effect of anisotropy in the permeability can be replaced by building the model on new scales, which are obtained by dividing the original coordinates by $1/\sqrt{k_n}$, where n represents the common coordinates x, y, and z. As previously mentioned, the greatest disadvantage of the electrical analogy method is that the top flowline, the phreatic line, must be located by trial. The phreatic line is the upper limit in a granular medium above which no water flows. In an electrical system there is inherently no such limit, because the electrical current flowing through a model has only the limitations of the edges of the conductive medium. It is therefore necessary to establish in the model an insulating boundary at a location corresponding to that of the phreatic line and thus exclude the flow of electricity from that area in which water will not flow. The location of the electrical boundary is established by a process of trial and error. Since the phreatic line is at atmospheric pressure, the only type of head that can exist along it is elevation head. Therefore there must be a constant drop in elevation between the points at which successive equipotentials meet the top flowline. This is our guide when trying to find the phreatic line.

The work required to properly establish the phreatic line depends on the conductive material used in the model. One objective in doing the tests to be described was to try a new conductive material in

FIG. 2. COMPLETE SETUP FOR THREE-DIMENSIONAL TESTS

seepage problems solved by electrical analogy, which could be used successfully in a trial-and-error process.

The description of the tests conducted with this material will demonstrate the practical application of the electrical analogy method.

The New Conductive Material

The requirement for the conductive material was that it be homogeneous so that its electrical resistance would be constant and would remain so, within given limits, during the tests. The new material was made up of gelatin, glycerin, and water, and salt was added to make it an electrical conductor. Our first problem was to determine the best proportions between gelatin, glycerin, and water in a solution. From the results of tests, it was decided to use a mix consisting of 15 per cent gelatin and 15 per cent glycerin by weight, of the water used in the mix.

It has previously been found that the addition of glycerin contributes to both life and strength of the gelatin mix. Too little content of gelatin makes the samples soft and sticky. In the tests one of the commercially available gelatin powders was used and chemically pure glycerin. The conductivity was changed by adding common table salt. The gelatin could be melted and used over again several times. Decay of the solution was prevented by adding beta naphthol. Experience indicated that 40-50° C was a satisfactory temperature at which to mix.

With voltage of 0-10 volts, a proportional increase of current with the increase of voltage drop in the material was noticed, as shown in Fig. 1. The same figure shows the electrical resistance as a function of the amount of salt added.

In the preliminary tests, direct current was tried. However, polarization of the material made it necessary to change to alternating current.

The electrical analogy method tests with the new conductive material had to be planned so as to give

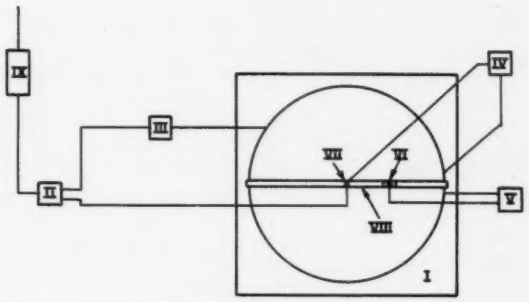

FIG. 3. ESSENTIAL EQUIPMENT FOR THREE-DIMENSIONAL PROBLEMS

us valuable information about the properties of the material. First, the material had to be studied for homogeneity. This could be checked only by studying a seepage problem where the flownet is the same for several cross sections, as is the case for some single well problems. The flownet we may expect for these problems is a radial flownet which is the same for all radial cross sections through a given well axis.

Tests to Determine the Distribution of Equipotential Lines Around an Artesian Well

The first tests were to determine the equipotential lines around an artesian well for various penetrations of the well. For this purpose a setup was designed and built at the Laboratory of Soil Mechanics. We assumed in our tests that the replenishment of water withdrawn from the well would occur from all sides of the well. This assumption required a cylindrical-shaped boundary in the tests.

Equipment. The complete setup is shown in the photograph (Fig. 2). It included the following components, numbered as they appear in Fig. 3:

I. Waterproof cylindrical bank with an electrically nonconductive bottom. The side of the bank is made of a stainless steel plate 3 ft in diameter, which is a very good electrical conductor.
II. Variach with range between 0 and 125 volts, plugged to the voltage regulator.
III. Ammeter with range 0 - 10 amp.
IV. Voltmeter measuring the total drop between the cylindrical boundary and the well-probe.
V. Vacuum-tube voltmeter measuring the drop between the cylindrical boundary and any point of the model.
VI. Insulated probe, that makes contact only at its end, connected to the vacuum-tube voltmeter.
VII. Well-probe, with diameter of ⅛ inch. This probe, the model of the well-casing, is the outtake for the electricity.
VIII. Support for the well-probe and the insulated probe.

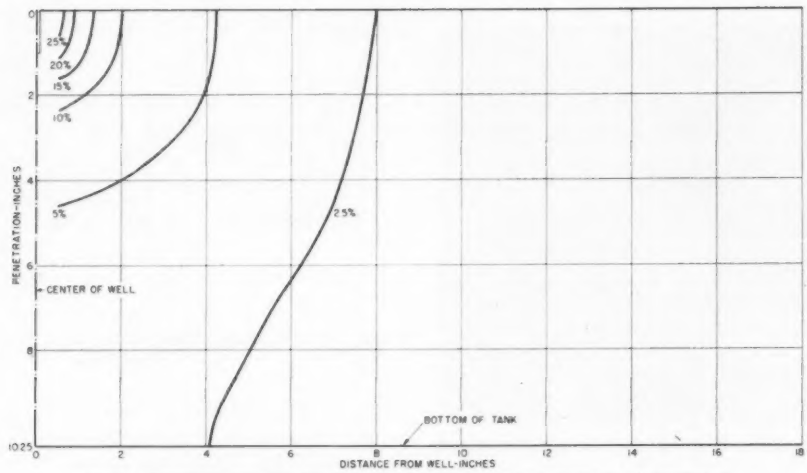

FIG. 4. EQUIPOTENTIAL CURVES FOR ONE-INCH PENETRATING ELECTRODE

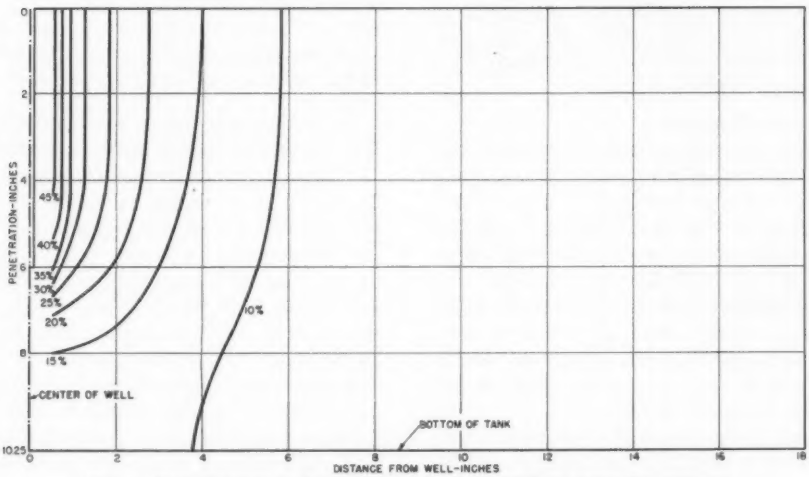

FIG. 5. EQUIPOTENTIAL CURVES FOR SIX-INCH PENETRATING ELECTRODE

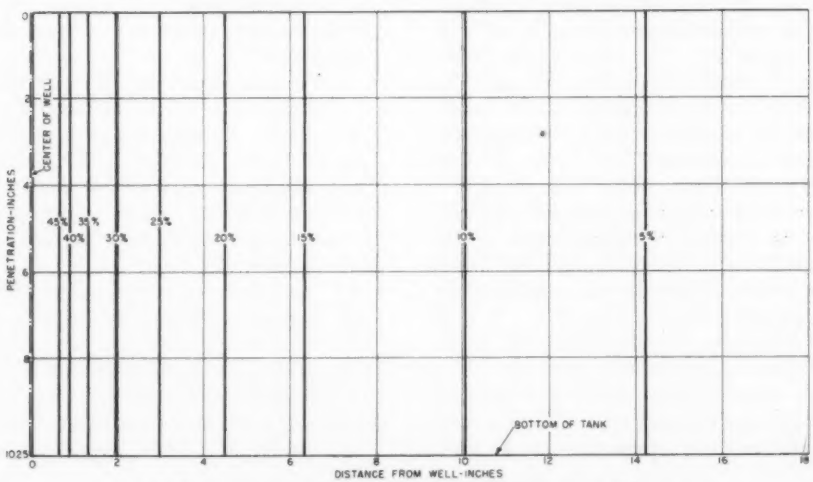

FIG. 6. EQUIPOTENTIAL CURVES FOR FULL PENETRATING ELECTRODE

IX. Voltage regulator used to stabilize the voltage from the electricity net which may vary somewhat because of the great consumption of voltage in other parts of the building.

The use of this equipment is not limited to well problems but can be applied to seepage studies in connection with excavations for bridge piers, caissons, or foundations of buildings.

Testing Procedure. A horizontal layer, 10 inches thick was poured in the tank of the flow-table. With the electrical connections made as outlined under the description of equipment, voltage was applied to the model. The potential at different points was determined by putting in the model the insulated probe, which made contact only at its end. The disturbance of the model generated by putting the probe in the model is negligible when a probe of reasonable size is used. In a radial vertical section potential readings were taken at 176 points.

For each of the ten tests we measured the electric current flowing in the model. The penetration depth of the well was varied one inch for every test. To ensure that the material was homogeneous, potential readings in several cross sections were taken. The values checked very well.

Interpretation of Test Results. For each case the equipotential lines are plotted for the following relative percentages: 5, 10, 15, 20 . . . 50 of the total potential drop between the boundary of the tank and the surface of the well-probe. Figures 4, 5, and 6 show the results of 1-inch, 6-inch, and full penetration of the well-probe.

For each test an average value of the electric current flowing in the model was calculated. Based upon these values, a discharge chart (Fig. 7) was plotted. According to the theory of the analogy, the flow of water in the prototype is proportionate to the flow of electric current in the model. This fact can be used to find the relative discharge of a well.

Knowing the current, I, flowing in the model for different penetrations of the well, we take the ratio I/I_{max} ($\sim Q/Q_{max}$) and plot this value as a function of $h_{well\ penetration}/h_{total\ thickness}$ and thus get the chart in Fig. 7.

Discussion. Several interesting features of flow into a well are apparent from the distribution of the equipotential lines. Common for all figures is the large potential loss close to the well.

The changes in the equipotential lines when the penetration depth of the well is varied, are also interesting to recognize.

For a very shallow well-penetration in the layer, the equipotential curves close to the well-probe are spherical. Further from the probe the curves become increasingly straightened out. For full penetration, the equipotential lines are straight and vertical.* The discharge chart, Fig. 7, gives the efficiency of the well as the penetration increases.

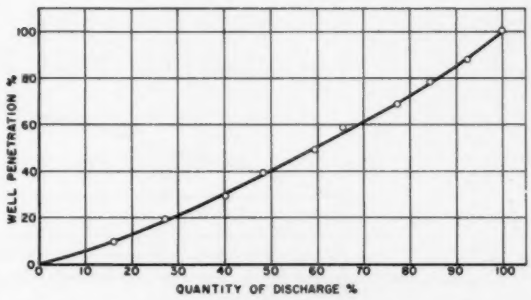

FIG. 7. DISCHARGE CHART FOR AN ARTESIAN WELL

Tests to Determine the Free Surface Around a Gravity Well

Introduction. From our first tests we could conclude that the new conductive material of gelatin could be used in electrical analogy method tests. The tests now to be described show the use of gelatin in problems where the phreatic surface has to be determined by a trial-and-error adjustment. In this case the free surface around a gravity well, partially penetrating a saturated sand layer, was determined.

Equipment. The equipment from the first series of tests could have been used. However, this time a wedge-shaped model, formed in a specially made box, was used as shown in Fig. 8. The electrical equipment was the same as for the first series of tests.

The Model. In the electrical model, the free surface is the locus of points, or lines, along which the potentials vary linearly above the base of the system. To satisfy the boundary conditions at the well-casing, we have to put in a resistance strip reaching from the assumed water level in the well to the original ground-water surface in the porous layer. The top of this resistance wire must have the same potential as the outer boundary of the layer.

The equipotential lines were traced on one of the long sides of the model by a probe connected to the vacuum-tube voltmeter. (See Fig. 8.)

The surface of the model was cut with a wire as outlined under the testing procedure. Figure 9 shows the final free surface for one of the tests.

Testing Procedure. The model to be tested was connected as shown in Fig. 8. The voltage drop between the boundary of the layer and the well-probe was 1 volt. The total voltage drop was divided into

* In Reference 8, Muskat outlines a theoretical mathematical solution for similar problems. However, the complexity of the mathematics is a disadvantage of this method.

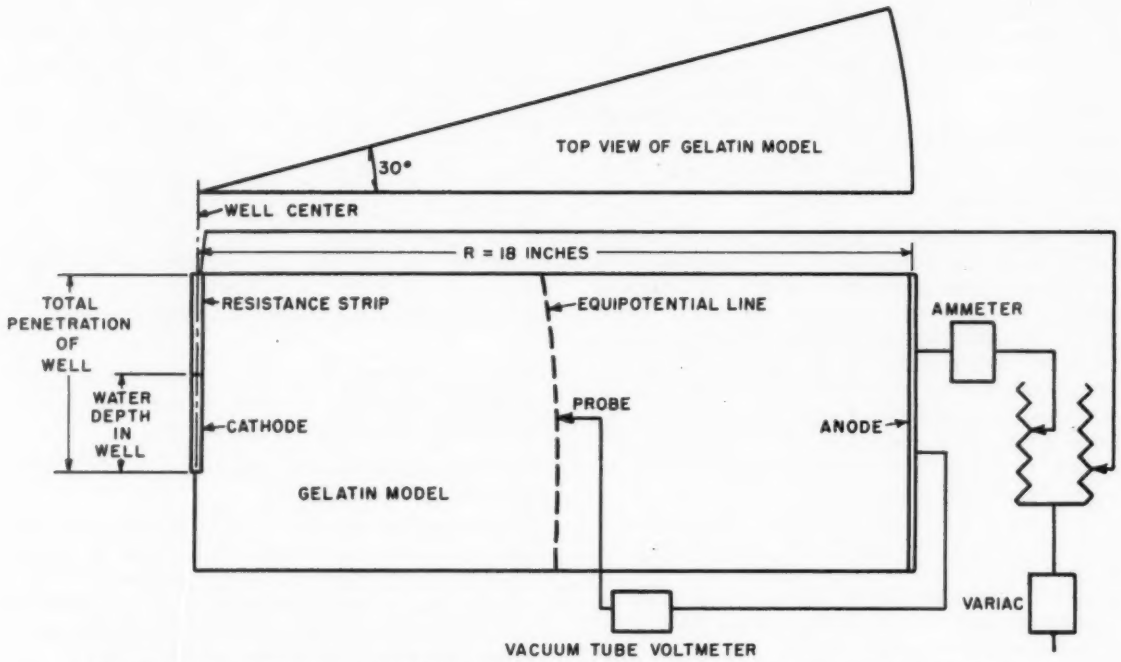

FIG. 8. ESSENTIAL EQUIPMENT FOR TEST TO DETERMINE THE FREE SURFACE AROUND A GRAVITY WELL

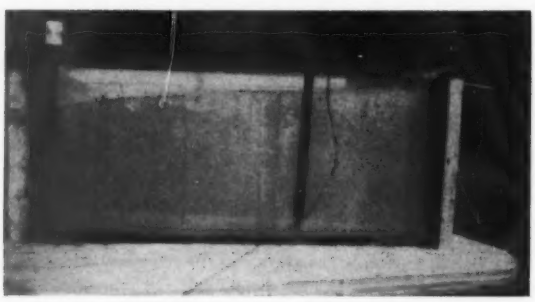

FIG. 9. THE FINAL FREE SURFACE

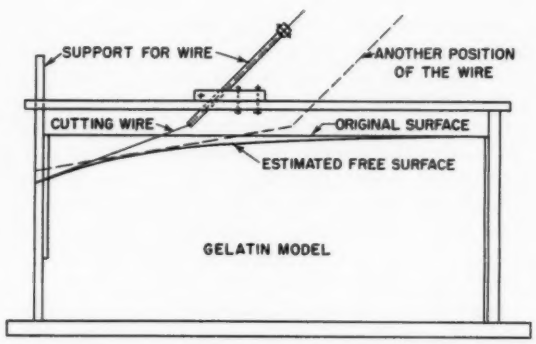

FIG. 10. PROCEDURE OF CUTTING THE SURFACE OF THE GELATIN MODEL

ten equal parts and the equipotential lines were located which corresponded to each of the ten increments of voltage. Based on these lines, the first approximation to the free surface was found by marking the point on each equipotential line which indicated that fraction of the total drawdown which corresponded to the voltage of the equipotential line of the total voltage drop. The model was cut along this line, and then the process was repeated until the true phreatic surface was located. Figure 9 shows one of the models.

The surface of the model was cut by using a wire, which worked best when it was heated. Figure 10 shows the way the surface was cut. The wire, while cutting, was always tangential to the estimated free surface.

Conclusion. The results of the tests justified the conclusion that the new material may be very useful in problems where the phreatic surface has to be determined by a trial-and-error adjustment. The material is easy to mix and form, and is very economical because it can be remelted and poured in new models several times.

(Continued on page 32)

PORCELAIN ENAMELS FOR ALUMINUM

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J. I. Mueller

The purpose of this paper is to present in condensed form a review of the work done in the Department of Ceramic Engineering since 1949 on the problems involved in porcelain enameling of aluminum. This work, most of which has been reported in the form of undergraduate theses by Glen J. Asher,[1] William F. Carroll,[2] E. C. Subbarao,[3] and Donald R. Stenquist,[4] attempted to develop a lead-free enamel.

The enameling of light metals is certainly in its infancy; in fact, the application of vitreous coating to aluminum on a commercial scale is still in its first decade of history, and enamels for titanium and magnesium are still in the laboratory stage.[5,6,7] High-lead glasses have been developed,[8,9] and several are available and being used commercially.[10,11] Lead-free glasses, including the phosphates, borates, and fluorides, have been studied by Jones.[12] Donahey and others[13] experimented with a series of lithium phosphate enamels. Commercial frit manufacturers have been doing considerable development work during the past several years, but little is available in the literature as to their results.

The application of a porcelain enamel adds greatly to the versatility of aluminum by reducing its exposure to atmospheric attack (oxidation and weathering) and increasing its eye appeal through the use of colors and decorative methods. The enameled aluminum surface, which is more durable than either the painted or lacquered surface, is also desirable for many architectural purposes. Moreover, an enamel may serve as a more satisfactory adhesive than the resin and other organic adhesives now being utilized in preparing the aluminum "honeycomb" structure under present development for aircraft,[14] since it would withstand higher temperatures.

The chief difficulty with enameling aluminum is its melting point, 1220° F (660° C), much lower than the fusion point of most commonly used ceramic raw materials. Although certain glasses have been melted at lower temperatures than this, they normally do not have the properties desirable for a metal coating,

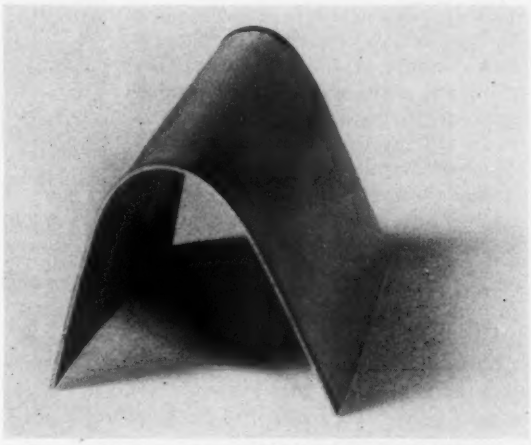

FIG. 1. SHEET OF 2S ALUMINUM WITH COMMERCIALLY APPLIED ENAMEL BENT AT ANGLE OF 120° TO SHOW HIGH ADHERENCE

FIG. 2. SHEET OF 2S ALUMINUM WITH COMMERCIALLY APPLIED ENAMEL SHOWING HIGH ADHERENCE AFTER IMPACT

namely, adherence to the metal, resistance to weathering, resistance to acid, and good color. Moreover, such enamels which are in current commercial use have a high lead content which produces toxic fumes during processing, thus creating an occupational hazard. Another disadvantage of these enamels is that they will fit only the aluminums of high purity, which do not have the high strength of some of the alloys. One advantage that aluminum coated with lead enamels has over steel covered with conventional enamels is its ability to withstand bending and cutting. Figure 1 gives graphically the extremely high adherence of a production enamel to aluminum, as indicated by the fact that the metal specimen has been bent to more than 120° without damaging the glass. Figure 2 shows resistance of the enamel to impact.

TABLE I

ENAMEL FRIT COMPOSITIONS
(Weight %)

Frit No.	Code*	Li_2O	Na_2O	K_2O	LiF	NaF	CaF_2	AlF_3	ZnO	PbO	Al_2O_3	Sb_2O_3	B_2O_3	Fe_2O_3	SiO_2	P_2O_5	V_2O_5
1	(A1)	.....	9.3	6.3	.....	2.1	.....	1.4	21.5	.....	17.0	.....	6.9	.....	.....	40.2	.....
2	(A2)	.....	11.1	7.5	.....	2.5	.....	1.7	6.4	.....	20.2	.....	8.3	.....	.....	42.3	.....
3	(A4)	3.1	6.4	5.7	.....	2.6	.....	1.7	6.7	.....	21.2	.....	8.6	.....	.....	44.0	.....
4	(A6)	2.9	6.0	5.5	.....	2.4	.....	1.6	6.3	.....	19.8	.....	8.1	6.2	.....	41.3	.....
5	(A7)	2.8	5.9	5.3	.....	.....	.....	.....	6.1	12.6	19.2	.....	7.9	.....	.....	40.2	.....
6	(C3)	.....	5.0	23.0	.....	.....	.....	.....	8.0	.....	30.0	.....	9.0	.....	.....	25.5	.....
7	(C6)	.....	9.4	6.3	.....	2.1	.....	1.4	5.5	.....	17.2	.....	7.0	.....	.....	35.8	15.3
8	(Su1)	.....	22.2	7.1	.....	2.3	1.2	1.6	.....	.....	7.7	5.8	19.9	.....	32.1	.....	.....
9	(Su4)	.....	25.0	3.8	.....	8.3	1.0	5.5	.....	.....	.....	5.0	29.7	.....	21.7	.....	.....
10	(Su8)	3.0	20.1	3.8	.....	8.3	1.0	5.5	5.9	.....	2.0	5.0	23.8	.....	21.7	.....	.....
11	(Su9)	3.0	20.3	5.0	8.4	.....	1.0	.....	6.0	.....	5.4	5.0	24.0	.....	21.9	.....	.....
12	(Su10)	6.5	15.0	.....	.....	8.4	1.0	5.6	7.0	.....	6.5	5.0	10.0	.....	35.0	.....	.....
13	(Su11)	.....	15.0	.....	7.5	.....	1.0	5.6	6.0	.....	6.5	5.0	10.0	.....	35.0	.....	.....
14	(St2)	11.4	20.1	5.0	.....	.....	1.0	.....	6.0	.....	5.5	5.0	23.8	.....	21.8	.....	.....
15	(St7)	5.6	21.4	5.3	.....	.....	1.1	.....	6.4	.....	5.8	5.3	25.2	.....	23.2	.....	.....
16	(St9)	17.0	19.8	4.7	.....	.....	0.9	.....	5.6	.....	5.2	4.7	22.5	.....	20.6	.....	.....

* Letter of code refers to initial of thesis author. (See reference list.) Number refers to frit number designated in the reference.

TABLE II

TEST RESULTS

FRIT NO.	FUSIBILITY	ADHERENCE	SURFACE	RESISTANCE		
				Cold Water (3 days)	Boiling Water (2 hours)	Acid (spot test)
1	Refractory	NT*	NT	NT	NT	NT
2	NT	Good (Cu)†	Good	Unsatisfactory	Unsatisfactory	NT
3	NT	Good (Cu)	Good	Good	Good	NT
4	NT	Good (Cu)	Good	NT	NT	NT
5	NT	Good (Cu)	Good	NT	NT	NT
6	(Soluble)	NT	NT	NT	NT	NT
7	Refractory	NT	NT	*NT	NT	NT
8	Refractory	NT	NT	NT	NT	NT
9	Fair	Poor	Poor	Excellent	Unsatisfactory	NT
10	Good	Excellent (o)‡	Good	Excellent	Unsatisfactory	Fair
11	Good	Excellent (o)	Good	Excellent	Poor	Good
12	Refractory	NT	NT	NT	NT	NT
13	Refractory	NT	NT	NT	NT	NT
14	Good	Excellent (o)	Good	NT	NT	NT
15	Fair	NT	NT	NT	NT	NT
16	Poor	NT	NT	NT	NT	NT

* No test.
† Copper replacement.
‡ Oxidation.

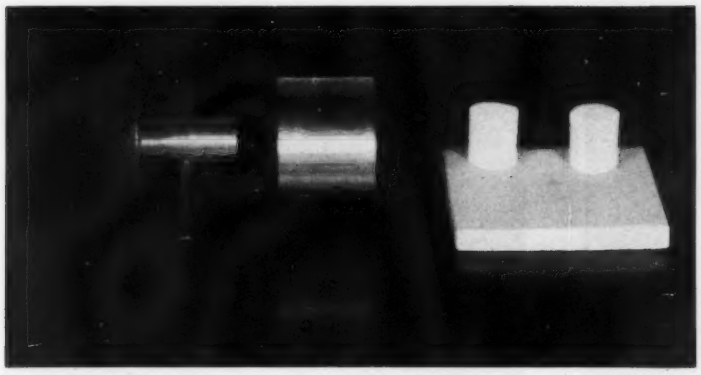

FIG. 3. MOLD AND PLUNGER WITH TYPICAL SPECIMENS OF PELLETS FORMED

Metal Preparation

The usual metal preparation for enameling is quite complex and somewhat costly, in that a chromite and caustic bath is required for initial dipping, and then the metal must be heated to between 900° and 1000° F to fix the coating so applied. Asher found that applying the enamel to 2S aluminum without any preliminary treatment was unsuccessful, but that raising the firing temperature of the enamel sheet to 1075° F for from five to fifteen minutes improved the adherence to a marked degree. He attempted to further improve the adherence by dusting the metal with cupric chloride before heating in hopes that, at an elevated temperature, an exchange reaction betweeen the aluminum and the cupric chloride would result in the formation of aluminum chloride, which would volatilize. The reaction, however, was extremely corrosive, and the method was discarded as uncontrollable. He next prepared a saturated solution of cupric chloride in 95 per cent ethyl alcohol. When the aluminum sheets were suspended in this bath, an electrochemical displacement took place after several minutes in solution, and a good deposition of copper was obtained. The latter method of preparing the metal seemed to increase the adherence of his phosphate enamels considerably. Carroll prepared his metal by suspending the sheet in solutions of copper chloride and alcohol, copper chloride and water, and copper sulfate in water, the latter being made slightly acidic by the addition of hydrochloric acid. The enamels applied to these surfaces had a tendency to crawl, and the crawling seemed worse on the sulfate-treated enamel than on the others. The adherence on the sulfate-treated specimen, however, was excellent, and the enamel could be removed only by flexing the metal. It was noted here that the separation appeared to take place within the copper layer and not at the metal-glass interface.

Subbarao, who tried Oakite, a commercial alkaline detergent, found that a 5 per cent solution warmed to 80° C was quite satisfactory. He further found that a 5 per cent solution of a trisodium phosphate, used at a rolling boil for five minutes, was equally satisfactory, and utilized the latter method in most of his work. When the metal specimens were dried and then enameled, their appearance was good while the enamel was hot, but, on cooling, the glass flaked off. Microscopic examination showed an extremely vesicular structure in the glass, but a thin coating of glass remained on the metal. When the metal was pre-heated to 1000° ± 20° for ten minutes, the oxide layer on the aluminum was increased, and this metal preparation gave by far the best adherence.

Enamel Compositions

The enamel compositions used in these four investigations are shown in Table I. In order to study to better advantage the fusibility and fluidity characteristics of the various enamels, a slight modification of the method reported by Marbaker[15] and Plankenhorn[16] was used. In this test the enamel was ground and formed by means of a mold and plunger (Fig. 3). The pellets were dried in an oven and then heated on a hot plate to drive off the organic binder and moisture used in the forming operation. They were then transferred to a block cut from insulating fire brick which kept the tile horizontal in one position, and, when tilted, inclined the tile at an angle of approximately 75°. The block and tile in horizontal position were placed in a small electric furnace maintained at a constant temperature of 1200° F. After five minutes the block was tilted so that the tile was inclined and heated in this position for an additional five minutes. Figures 4 and 5 show the block in the two positions. The results of typical fusion button tests are shown in Fig. 5.

Conclusions

The results of these investigations, as shown in Table II, indicate that satisfactory enamel for aluminum may be obtained from either a highly fluoro- or boro-silicate glass, or from a phosphate glass. The solubility under weathering conditions of the high alkaline glasses was not so good as might be desired; however, as indicated in Table II, some of these enamels did have a fair resistance to acid. The phosphate glasses, on the other hand, had a much higher resistance to weathering, although their acid resistance was poor.

The results of these investigations indicate that certain possibilities exist for the development of a satisfactory lead-free coating for commercially pure

FIG. 4. HOLDER SUPPORTING THE PELLETS IN HORIZONTAL POSITION

aluminum, utilizing either phosphate or alkaline-fluoro-silicate glasses. Investigations are being continued along these lines, as well as further study of the problem of metal preparation.

It would be most desirable, of course, to obtain lead-free enamels that would fit the high-strength alloys, although a clad aluminum, consisting of a high-strength base and a pure aluminum clad that could be enameled, might be satisfactory. Work in this direction is also getting under way.

FIG. 5. HOLDER SUPPORTING FUSION BUTTONS IN THE INCLINED POSITION

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Statistics on published technical literature reveal the need for translating devices. Reliable estimates indicate that nearly two-thirds of the world's engineering literature is published in English, but more than two-thirds of the world's professional engineers cannot read English, and an even greater proportion of English-speaking engineers cannot read other languages. This situation limits the effective use of the more than one million technical items published each year.—*Industrial Bulletin of Arthur D. Little, Inc.*, April, 1954.

Moisture Determination in a Circulating Refrigerant

(National Bureau of Standards, Summary Technical Report 1843, January, 1954)

A SIMPLE, RAPID METHOD for determining the water content of a circulating refrigerant of the fluorocarbon group has been developed by A. W. Diniak, E. E. Hughes, and M. Fujii* of the National Bureau of Standards. Based on the change in electrical resistance of an electrolytic film as it absorbs water vapor, the method is an application of the electrical conductivity method[1] for determining water vapor in gases, developed and used for many years by E. R. Weaver of NBS. The method is highly sensitive, gives accurate results, and does not require the removal of a sample from the circulation cycle. Determinations can be made repeatedly without difficulty, making it possible not only to determine the water content of the refrigerant but also to follow and determine continuously its instantaneous water content before and after passage through a drier.

In commercial refrigeration systems the presence of water in the refrigerant constitutes a serious problem because freezing of the expansion valve and corrosion are always possibilities. Until now there has been no completely satisfactory procedure for determining the moisture content of a circulating refrigerant. Although several good methods for determining the moisture content of refrigerants in static containers are available, none of these is readily adaptable to a circulating refrigerant, chiefly because they require the removal of large samples, which would upset the steady state of the cycle. Such methods are also time-consuming and require much experience with the method involved. In contrast, the NBS method is very quick, simple, and convenient. Once a sampling and a return point have been placed in the system, the measuring apparatus can be quickly connected and a determination made in 15 or 20 minutes.

The principle of the method has been used at NBS for some time, chiefly to measure small amounts of water vapor in gases. A thin film of hygroscopic material—usually a mixture of sulfuric and phosphoric acids—is spread over the surface of a solid insulator between metallic electrodes in a pressure-tight enclosure. The electrolyte tends to reach equilibrium with the water vapor in the surrounding gas and to form a solution whose electrical conductance is a measure of the concentration of water vapor in the gas. This conductance is indicated by a simple electronic circuit and a microammeter.

A gas of known moisture content is used to calibrate the film after each reading. By adjusting the pressure of the comparison gas until the same conductivity reading is obtained for both the known and unknown gas, the two gases can be made to have the same water concentration. The unknown water content can then be calculated from the two pressures and the known water content of the comparison gas at atmospheric pressure.

Usually the comparison gas has been saturated at a high pressure (about 1000 psi) and room temperature in a specially designed saturator and then permitted to expand for use. For very dry systems a secondary comparison gas is employed. This is simply a quantity of fairly dry air whose moisture content has been previously determined by comparison with the saturated air.

Because of the pressure relationships involved and because a liquid would wash away part of the hygroscopic film, the electrical conductivity method can only be used to make moisture determinations of samples in the gaseous state. Thus, in the equipment constructed at NBS, a very small amount of the circulating refrigerant is "detoured" from the system, vaporized by heating, passed through the pressure chamber containing the hygroscopic film, and returned to the suction line for recirculation.

To prevent fractionation which would take place if only a part of the liquid sample were vaporized, it is necessary to withdraw the sample through a capillary tube so that the entire sample may be continuously vaporized. The capillary tube, dipping into the main stream of liquid refrigerant, carries a portion of the liquid to an electrical resistance heater which vaporizes the refrigerant. To ensure complete vaporization, the tubing containing the liquid refrigerant is wound loosely around the heater in the form of a helix and is thermally insulated from the ambient air. The vaporized refrigerant is then led to the detector block

(Continued on page 32)

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* Mr. Fugii received his degree of B.S. in Industrial Engineering from the University of Washington in 1949. *Ed.*

[1] Moisture determination by electrolytic film, NBS Technical News Bulletin 32, 13 (February 1948).

Note: For further technical details on the application of the electrical conductivity method to circulating refrigerants, see The determination of water in freon-12 circulating in a refrigerating system, by Albert W. Diniak, Ernest E. Hughes, and Minoru Fugii, *Refrigerating Engineering* (in press). (This article appeared in the February, 1954, issue of *Refrigerating Engineer*, on page 56. *Ed.*)

Left to right: Prof. M. P. Coopey, Oregon Agricultural College, general chairman of the Road Conference; F. G. Gramatky, contractor in California; B. F. Ostergren, managing director, County and Local Roads Division, American Road Builders' Association; G. A. Riedesel highway research engineer, Washington State Institute of Technology. —*All photographs courtesy of* PACIFIC BUILDER AND ENGINEER.

Northwest Road Builders Convene at Corvallis

THE EIGHTH NORTHWEST CONFERENCE on Road Building met February 10 and 11, 1955, on the campus of Oregon State College, attended by 200 engineers and public officials. This annual conference alternates between Oregon State College and the University of Washington.

The opening address by George W. Gleeson, Dean of Engineering at Oregon State College, stressed the importance of the automobile in our economy, and the failure of our highway investment to keep pace with our investment in highway vehicles.

F. Gunner Gramatky, a contractor from Sacramento, California, discussed the technology of soil stabilization. He emphasized that the undertaking of the scientific basis for stabilization is not sufficient for the successful completion of the job. Construction practice must still rely upon empirical rules. His talk emphasized the value of Portland cement as a stabilizing agent, even in small quantities. Excessive cement is undesirable because it produces a weak structural slab rather than a strengthened granular base. He felt that the expense of stabilization was generally an investment which brought greater return than did alternate comparable expenditures.

The group showed great interest in John R. Gray's recital of his efforts to plan a comprehensive road program in Umatilla County, where he is County Engineer and Roadmaster. Mr. Gray's first step after his appointment was to undertake a methodical study of the physical and financial resources of the county, and to analyze how the local road needs could best be met. The resulting program gives evidence that a rational procedure can provide better roads.

The Thursday afternoon session started with a lively talk by Charles F. Craig, engineer with the J. H. Baxter Co. of Oregon, on the efficient design of timber highway structures. Mr. Craig pointed out the economies that result from specifying proper grades of timber.

Ben F. Ostergren, who is Managing Director of the County and Local Roads Division, American Road Builders' Association at Washington, D. C., discussed national trends in county and local road financing. He showed how present tax practices developed out of the experience of the past fifty years.

Some interesting phases of the Washington state gas-tax allocation study were described by G. A. Riedesel, Highway Research Engineer at Washington State College, who had directed the investigation. Mr. Riedesel explained the proposal for dividing gas-tax funds among the counties, based upon rural car registrations, estimated annual road costs, and availability of other funds in the individual counties.

The function of a state highway research council was discussed by the present writer. Considerable data on research administration in various states are available in a 1953 report of the national Highway Research Board, issued as Special Report 15 (publication No. 284). The council in the state of Washington differs from state research organizations elsewhere in its broad representation from all affected governmental and user groups. This factor is helpful in achieving better public understanding and legislative acceptance of the research findings. Projects completed or in progress cover such topics as highway classification, toll roads, county gas-tax allocation, subgrade soil studies, and a broad review of highway tax policy.

The Conference banquet was held Thursday evening at the Hotel Benton, with Sidney King of the

Left to right: C. E. Minor, research engineer with the Washington State Highway Department; C. F. Craig, engineer with the Baxter Company of Oregon; Prof. R. G. Hennes, University of Washington, chairman of the Washington State Council for Highway Research; J. H. McLerran, research engineer at the Washington State Institute of Techno'ogy.—*All photographs courtesy of* PACIFIC BUILDER AND ENGINEER.

Oregon State Motor Association presiding. The featured speaker, Julia Butler Hansen, described the value of factual research in solving the problems of highway legislation—a field in which she has achieved national recognition. Mrs. Hansen is Chairwoman of the Western Interstate Committee on Highway Policy, and of the House Roads and Bridges Committee of the Washington State Legislature. She has had a leading role in the evolution of the Interim Legislature Committee as a successful agency for the development of objective highway policy.

Friday morning was devoted to the design and construction of asphalt pavements. A panel on construction practices was composed of O. C. Jessup, of the Contractors Equipment Corporation; George Hamson of the Columbia Equipment Company; Oscar A. White, Oregon Highway Department; and Al Shurtz, Asphalt Equipment Company. This fruitful discussion of equipment operation and inspection was followed by a resume of the general field by Fred N. Finn, District Engineer of the Asphalt Institute, Sacramento, California. The morning session closed with a talk by Carl E. Minor, Materials and Research Engineer of the Washington State Highway Department, who talked on his experiences in the design of asphaltic paving mixes.

The Oregon State Highway Engineer, R. H. Baldock, opened the final session with a description of President Eisenhower's plan for rebuilding the nation's highways. This is the estimate of $100 billion cost to improve the country's public road system during the next ten years. Public attention has been largely attracted to that portion of the program which deals with the 40,000-mile system of interstate highways. This job would become the financial responsibility of the Federal government to a major extent. Mr. Baldock stated, "While it is possible to finance the interstate system under the terms outlined, it will be quite difficult to complete the other portions of the federal-aid system, costing about $41 billion, and the city and county systems, costing $33 billion, in a 10-year period, without major increases in road-user and property taxes. It has been estimated that such a program would require the equivalent of about a four-cent gas tax over the nation besides an increase in property taxes. . . . 15 years is a more reasonable time for all systems."

A panel discussion followed, on the practical application of standards for signing and striping, in which the participants were F. B. Crandall, Traffic Engineer; W. O. Widdows, Assistant Maintenance Engineer; and J. A. Head, Assistant Traffic Engineer, all of the Oregon State Highway Department.

James H. McLerran, Highway Research Engineer at the State College of Washington, described current research on the use of agricultural soils maps for highway engineering purposes. With the completion of this project it will be possible for county engineers, and others, to correlate their road building experiences with agricultural soil classification. The county soils maps will thus permit them to predict road performance throughout the mapped area on the basis of their individual road experiences.

The final talk of the Conference was given by Bob Glenn of the Institute of Transportation and Traffic Engineering, University of California. He described some of the work of the Institute, and showed how progress toward better roads can be aided by the ideas that germinate on the college campus.

The chairmen for the four sessions were: Professor James Gray, Oregon State College; Ben B. Irving, President of the Association of County Engineers of Oregon; B. A. Vallerga, Managing Engineer, Pacific Coast Division, The Asphalt Institute; M. Popovich, Assistant Dean of Engineering, Oregon State College.

Gordon Wyatt was chairman of the Student Committee. Professor Martin P. Coopey was general chairman for the Conference.

ROBERT G. HENNES
University of Washington

Engineering Research Dividends

Recent theses submitted for advanced degrees from the College of Engineering, University of Washington, will regularly appear in abstract form in *The Trend*. Complete copies of these theses are available for reference at the University of Washington Library. Address inquiries to the Director of the Engineering Experiment Station, University of Washington, Seattle 5.

KOLB, K. M., "The Effects of Cerium on Aluminum Alloys." M.S. in Metallurgical Engineering.

The effects of cerium additions on aluminum and three aluminum alloys were investigated with respect to their tensile properties as indicated by Brinell hardness. The limit of solid solubility of cerium in pure aluminum at eutectic temperature was determined approximately by means of cooling curves. Detailed results are presented for the following alloy compositions: 17S aluminum control, and 17S aluminum plus 0.6 and 4.1 per cent cerium; 24S aluminum control, and 24S aluminum plus 0.5 and 4.0 per cent cerium; 112 aluminum control, and 112 aluminum plus 0.4 and 3.6 per cent cerium. The effects of cerium on the aging of these alloys was investigated, at room temperature for the 17S group, and at 190° C and 230° C for the 24S group. The 24S group were carried through the over-aging stage. It was found that cerium tends to retard the aging process and, in amounts greater than about 0.5 per cent, to reduce the strength developed by both 17S and 24S aluminum alloys; in the latter group cerium tends slightly to retard over-aging. No beneficial grain-refining action from cerium was found for any of the alloys made. The effects of cerium additions of from 0.17 to 11 per cent to pure aluminum were determined and are shown in cooling curves. The hardness of cerium-aluminum alloys in this range is apparently due to the solid solubility effect and varies almost linearly with the percentage of cerium. The solid solubility of cerium in aluminum at 639° C proved to be about 0.4 per cent.

LEE, C. T., "On the Deflection Function for a Particular Case of a Cantilever Triangular Plate." M.S. in Aeronautical Engineering, 1954.

A method of finding the deflection function is presented here for a cantilever isosceles triangular plate, with an angle of 90° at the free tip. It is assumed that the load is symmetrical with respect to the line from the tip and normal to the clamped edge. The load is always such that the deflection remains small. Under these conditions, a deflection function may be assumed in the form of a polynomial in x and y (using rectangular Cartesian coordinates), with unknown coefficients or parameters to be adjusted. By suitable tabulation and arrangement of the polynomial equation and its corresponding derivatives, later substitution into the equations for the boundary conditions will lead to a set of simultaneous algebraic equations containing the unknown parameters. Solutions of these equations yield all the unknown parameters in terms of one (or more) selected parameters. These selected parameters can be determined by the Rayleigh-Ritz method, by satisfying the plate equation at certain discrete points, or by matching the function with the experimental deflection surface at particular points.

BORIBHANDH, K.-J., "Survey of Methods for Finding Span Load Distribution for Sweptback Inelastic Wings." M.S. in Aeronautical Engineering, 1954.

Three well established methods for calculating the span loading of swept wings are analyzed briefly, with emphasis on the Multhopp method. Two other short methods are discussed, together with the Küchemann method. The latter is fully explained in detail with comparison to the Weissinger method.

Calculations by the Küchemann method were made on two wings. The wings were identical in planform, having a sweep-back angle of 45° at the quarter-chord line, an aspect ratio of 6 and a taper ratio of 0.5. One wing is uncambered and untwisted and has an NACA 64A010 airfoil section normal to the quarter-chord line. The second wing is cambered and has a geometric twist. It has a 10° washout of the tip and employs an NACA 64A810, $a = 0.8$ (modified) airfoil section normal to the quarter-chord line.

Results of these calculations are compared with those obtained through the Weissinger method. Comparisons with two other methods on two other wings are also presented. An attempt at correction of the Küchemann method for predicting the effect of camber was made without much success.

RIDDHAGNI, B., "Comparison of the Velocity Profile of a Steady Shock Wave in Grad's and Broer's Theories." M.S. in Aeronautical Engineering, 1953.

A study is made of two shock wave profile theories: the thirteen moment theory of Grad, and the Burnett-Broer theory. The results are as fo" ɔws:

1) To the first approximation, the correction due to the Burnett terms as compared to the Navier-Stokes terms is small.

2) The Burnett terms correction makes the downstream side flatter and the upstream side steeper than the Navier-Stokes profile.

3) The thirteen moment curve is considerably flatter than the Navier-Stokes profile.

4) The thirteen moment approximation uses numerical integration, while a power-series expansion is used in the Burnett-Broer approximation.

DOUGALL, W. S., "Second Order Approximation to the Skin-Friction on a Flat Plate in Slip Flow at High Mach Numbers." M.S. in Aeronautical Engineering, 1953.

A method of solution for the laminar compressible boundary layer equations of slip flow in two dimensions is given which involves reducing the energy equation to the momentum equation. A third order differential equation results from the reduction which is integrated by numerical methods. The Prandtl number is taken as unity and the viscosity temperature relation of Chapman and Rubesin, $\mu \sim T$, is used. The effect of slip at the surface, and a temperature jump related to the slip are considered. Calculations indicate that for a flat plate the slip velocity will cause an increase in the skin-friction of 6.60 per cent as compared to 8.90 per cent obtained by Maslen in NACA TN 2818 for a similar problem.

What Is Happening to the Liberal Arts?

(Continued from page 1)

The fourth of the observations which help to explain what has happened to the liberal arts is—let it be said gently—that they have proved themselves inflexible and unadaptable to the new demands made upon them. Too often their spirit has been haughty and pedantic. The special needs of teachers and engineers, for example, have been met grudgingly.

Perhaps my analysis thus far has left the impression that the traditional values of the liberal arts are being lost and that the loss is not great. This would be an impression unintended. The values which have been associated with the liberal arts should always be conserved in education. But it is not subject matter which has produced those values—it is rather the way in which those subjects have been taught.

Whatever happens to the traditional liberal arts as the core of higher education, one may be optimistic as to the eventual preservation of the "liberal" values which have always been identified with them. The first reason for such optimism is that "liberal" values will be discovered in the new subjects in the curriculum.

If history, for example, teaches men patience and humility, is there any reason to believe that these same values cannot be derived from geology or nuclear physics? Is the mastery of a declension fundamentally a more "learned" accomplishment than a knowledge of formulae in organic chemistry? Does the beauty of poetry or painting affect mind or character more than insight into the symmetry of suspension bridges?

The second note of optimism comes from the gradual adaptation of the liberal arts to new interests and needs. Pressures of time, of vocational demand, of a vastly expanding curriculum, will no longer permit concentration of attention exclusively upon the liberal arts, but this does not mean that the informative and cultural values of such studies must necessarily be forsworn.

Fewer students now know Latin, but probably more are taking courses in etymology and in classical literature in translation. Survey courses in the history of civilization and philosophy may not produce historians and philosophers, but they will introduce many people to the fields. Thruout the liberal arts a spirit of adaptability is growing.

My third observation is that in the future, highschools may introduce students to liberal arts earlier than is done at present. The complaint that the first years of college duplicate too much the work of the highschools is sound and should bring about some withdrawal by the colleges from preparatory work. There may be room here for sound educational adjustment on the part of both colleges and highschools.

To summarize, I believe that the liberal arts as a group of subjects may not again regain their dominant position in the curriculum, but their liberal values will continue to survive in a variety of forms.

Notes and Comments

NEW RESEARCH PROJECTS

Project No. 167. Highway Test Tract. M. I. Ekse, Associate Professor of Civil Engineering, Supervisor; D. H. Danielson, Research Assistant.

Project No. 168. Flutter Problem Investigation. H. C. Martin, Professor of Aeronautical Engineering, Supervisor; F. Rattaud, Research Assistant.

Project No. 169. A Study of Railway Landslides in the Pacific Northwest. R. G. Hennes, Professor of Civil Engineering, Supervisor; S. H. Hawkins, E. L. McCoy, Research Assistants.

Project No. 170. The Design and Construction of a Portable Schlieren Apparatus. R. E. Street, Associate Professor of Aeronautical Engineering, Supervisor; W. E. Fagerberg, Research Assistant.

Project No. 171. Operating Conditions in Supersonic Tunnels. R. E. Street, Associate Professor of Aeronautical Engineering, Supervisor; G. G. Upton, Research Assistant.

Project No. 172. A Study of Stress Concentration. B. D. Mills, Jr., Professor of Mechanical Engineering, Supervisor; R. K. Chakrabarti, Research Assistant.

Project No. 173. New Techniques in Photoelasticity. E. E. Day, Professor of Mechanical Engineering, Supervisor.

Project No. 174. A Study of Broad-Band Waveguides. G. Held, Assistant Professor of Electrical Engineering, Supervisor; T. S. Chin, Research Assistant.

Project No. 175. Automatic Control Analogue. P. L. Balise, Assistant Professor of Mechanical Engineering, Supervisor; G. R. Flynn, Research Assistant.

Project No. 176. Sodium Sulphite Spent Liquor Recovery Processes. J. L. McCarthy, Professor of Chemical Engineering, Supervisor; M. P. Lung, Research Assistant.

Project No. 177. Instrumentation for the Aeronautical Engineering Structural Laboratory. R. C. Weikel, Associate Professor of Aeronautical Engineering, Supervisor; C. Reuss, Research Assistant.

Project No. 178. WASHO Test Road Data Analysis. M. I. Ekse, Associate Professor of Civil Engineering, Supervisor; R. W. Long, Research Assistant.

Project No. 179. Spray Drying. R. W. Moulton, Professor of Chemical Engineering, Supervisor; V. R. S. Arni, Research Assistant.

ENGINEERS IN THE NEWS

The paper on "A Critical Appraisal of Sewerage Design and Operation in Washington," presented by **R. O. Sylvester,** Associate Professor of Civil Engineering, before the Pacific Northwest Sewage and Industrial Waste Association meeting held at Eugene, Oregon, last October 21, will be published this spring in *Sewage and Industrial Waste.* A limited number of reprints will be available.

D. D. McNelis, W. E. Fagerberg, and **J. R. Zedro,** graduate engineering students, have received $1000 scholarships from the Boeing Airplane Company. Both McNelis and Fagerberg have been EES research assistants the past year, McNelis working in electrical engineering on Project No. 162, the electromagnetic flowmeter, and Fagerberg in aeronautical engineering, on Project No. 170, the portable Schlieren apparatus. They will continue work toward their M.S. degrees. Mr. Zedro has had a teaching assistantship and will continue graduate work in mechanical engineering.

B. D. Mills, Jr., Professor of Mechanical Engineering, was on the program of the meeting of the Pacific Northwest Section of the ASEE held at the University of Idaho, Moscow, April 15-16. Title of his paper was "Teaching Aids—Friend or Foe?"

R. H. Bogan, Assistant Professor of Civil Engineering, will attend the meeting of the Purdue University Industrial Waste Conference May 9, 10, 11, at Lafayette, Indiana, where he will read a paper on "The Biochemical Oxidation of Synthetic Detergents."

Klaus Mai, former EES research assistant, who received his doctorate in chemical engineering in 1954, attended the meeting of the American Chemical Society in Cincinnati where he presented a paper co-authored by **A. L. Babb,** Assistant Professor of Chemical Engineering. The title was "Vapor-Liquid Equilibria of the Systems Carbon Dioxide-Hydrogen Sulphide-Sodium Carbonate-Sodium Bicarbonate-Sodium Sulphide-Water, and Carbon Dioxide-Sodium Carbonate-Sodium Bicarbonate-Water." Dr. Mai is now with the Proctor and Gamble Company in Cincinnati.

R. G. Hennes, Professor of Civil Engineering, was recently on the program of three meetings of highway organizations. He is chairman of the Washington State Council for Highway Research. On January 12 at the 34th annual meeting of the National Highway Research Board at Washington, D. C., his paper was entitled "Concepts of Incremental Cost Theory." On February 3 he spoke on "Street and

Highway Classification" before the 7th Annual Street and Highway Conference at Berkeley, and on February 10, on "State Councils for Highway Research" at the 8th Northwest Conference on Road Building, held at Corvallis.

H. C. Martin, Professor of Aeronautical Engineering, attended the San Diego convention of the ASCE, where he appeared on the program of the Engineering Mechanics Division, February 11, with "Analysis of Complex Trusses by a Method of Unknown Joint Displacement."

NEW REPRINTS

Reprint No. 86. "Olivine-Silica Molding Sands." William A. Snyder, Gilbert S. Schaller, *Am. Foundryman,* June, 1954.

Reprint No. 87. "Ammonium Recovery from Ammonium Sulphite Spent Liquor by Ion Exchange Processes" (*Sulphite Spent Liquor IV*). Aaron E. Markham, Joseph L. McCarthy, *TAPPI,* Vol. 37, No. 8 (Aug., 1954).

Reprint No. 88. "Equilibrium Distribution of Ammonium and Other Ions Between Cation Exchange Resins and Aqueous Solutions" (*Sulphite Spent Liquor* V). V. F. Felicetta, A. E. Markham, Joseph L. McCarthy, *TAPPI,* Vol. 37, No. 10 (Oct., 1954).

Reprint No. 89. "An Electronic Distance Relay Using a Phase-Discrimination Principle." F. R. Bergseth, *Pow. App. and Systems,* Oct., 1954.

Reprint No. 90. "Continuous Countercurrent Ion Exchange: Part I. Resin-Particle-Settling Rates in Spinner Columns." J. Olin, W. W. Koenig, A. L. Babb, J. L. McCarthy, *Chem. Engg. Prog.,* Symposium Series, No. 14, Vol. 50 (1954).

Reprint No. 91. "Continuous Countercurrent Ion Exchange: Part II. Mass Transfer Rates in Spinner Columns." W. W. Koenig, J. Olin, A. L. Babb, J. L. McCarthy, *Chem. Engg. Prog.,* Symposium Series, No. 14, Vol. 50 (1954).

Reprint No. 92. "Harmonic Analysis for Nonlinear Characteristics." L. J. Lewis, AIEE, *Communication and Electronics,* Jan., 1955.

Reprint No. 93. "Method of Forming a Broad-Band Microwave Frequency." A. E. Harrison, R. E. Wall, *Trans. of the I.R.E. Professional Group on Microwave Theory and Techniques,* Jan., 1955.

Reprint No. 94. "Scintillation Counter for Vapor-Phase Analysis." A. L. Babb, K. Mai, *Nucleonics.* (Ordered)

Reprint No. 95. "Construction and Application of Membrane Analogs." W. E. Rogers, *Annals, Instrumentation.* (Ordered)

U. of W. Motor Vehicle Courses Maintain Interest

TWO OF THE UNIVERSITY COURSES aimed at safer and more efficient operation of motor vehicles recently drew a total of over 200 registrants, chiefly from the Northwest and Canada.

The 12th Annual Motor Vehicle Fleet Supervisors Training Course was held at More Hall, March 14-18, with Professor Amos E. Neyhart, Administrative Head, Institute of Public Safety, Pennsylvania State University, as leader and consultant. Professor Neyhart, who is Consultant on Road Training for the American Automobile Association, has participated in this course since its inception. The course was conducted by the College of Engineering and sponsoring groups including a number of local and national organizations.

The general purpose of the course is to acquaint motor vehicle fleet supervisors with the latest practical methods of operation and supervision. Aspects of driver selection which Professor Neyhart discussed included "tools of selection," interviewing, psychological testing devices, and traffic road tests. The use and value of records, analysis and interpretation of accidents, development of driver-trainers, and human relations, were some other topics on the program.

Paul H. Coburn of Chicago, Director of Motor Transportation Division, National Safety Council, conducted the lecture-discussions devoted to creating and maintaining driver interest.

On March 21-23, the College of Engineering, with cooperating agencies, conducted the 4th Annual Motor Vehicle Maintenance Conference. This course was divided into panels for consideration of different types of motor vehicles (light, medium, and heavy duty), and the kind of transportation for which they are used. Besides the motor divisions, personnel divisions, such as highway, utilities, and law enforcement, met to discuss their respective problems linked with maintenance.

The 155 registrants for this course included a number of engineers in charge of maintenance at various eastern automobile manufacturing centers.

August 29 to September 2 the Advanced Workshop for High School Teachers in Driver Education and Training will be held at More Hall. To qualify for registration, a teacher must have completed the basic course of 40 hours or its equivalent. As usual, Professor Neyhart will direct the instruction.

Applications for any of these motor vehicle courses should be addressed to the course director,

Professor Fred H. Rhodes, Jr.
Civil Engineering Department
University of Washington

ANALYSIS OF TWO- AND THREE-DIMENSIONAL GROUND-WATER FLOW

(Continued from page 20)

Summary

The general principles of the analysis of two-dimensional and three-dimensional ground-water flow by electrical analogy have been outlined, and the practical application of this method, made by tests with a new conductive material, has been described. This material consists of gelatin, glycerin, water, and salt.

Tests were made successfully with this material to determine the potential distributions around an artesian well, varying the penetration of the well, and also to determine the free surface around a gravity well.

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MOISTURE DETERMINATION IN A CIRCULATING REFRIGERANT

(Continued from page 25)

—a specially built, pressure-tight enclosure containing the moisture detecting element. By manipulating three control valves in the detector block, either refrigerant vapor or the comparison gas can be caused to flow past the hygroscopic film. However, the detector block is so constructed that the flow of refrigerant vapor through it is never interrupted; it is merely cut off from the detecting film. Condensation of the refrigerant in the detector block is prevented by placing the heater near enough to keep the refrigerant heated to just above its saturation temperature at the pressure of the liquid line. After leaving the detector block, the refrigerant vapor passes through a regulating valve which controls and limits flow through the sampling circuit; it then returns to the main line of the refrigerating system for recirculation.

To establish the validity of the electrical method for moisture determinations in a refrigerant, NBS compared results obtained by this method with the results of gravimetric determinations by the phosphorus pentoxide absorption method. Both types of determinations were made on the same or similar samples of refrigerant at the same, or very nearly the same, time. No important discrepancy was found between the results obtained by the two methods.

U. of W. and Seattle City Light Undertake Computer Studies

A new venture in cooperative power-system research, recently submitted to the University by Seattle City Light, has been made possible by extension of the University's computing facilities, including an IBM Type 604 electronic computer. The project, which will be directed by Dr. Laurel J. Lewis of the Department of Electrical Engineering, is planned to get under way June 1.

A major objective is to extend the application of digital computers to power-system problems. Typical studies may include problems of load-flow and the scheduling of hydroelectric operation in relation to the Northwest Power Pool. This new program will supplement and perhaps extend the analytical procedures commonly handled on power-system network analyzers.*

* See "Power-System Analysis: A Problem in Dynamics," by L. J. Lewis, *The Trend in Engineering*, January, 1955.

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